Marine Fisheries REVIEW

September 1979

National Oceanic and Atmospheric Administration • National Marine Fisheries Service

ANGLING and ARTIFICIAL REEFS

Marine Fisheries REVIEW

On the cover: Artificial reefs prove attractive to both fish and anglers.

Articles *September 1979*

Vol. 41, No. 9

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Richard A. Frank, Administrator
Terry L. Leitzell, Assistant Administrator for Fisheries

National Marine Fisheries Service

Managing Editor: W. Hobart

Marine Fisheries Review (USPS 090-080) is published monthly by the Scientific Publications Office, National Marine Fisheries Service, NOAA, Rm. 450, 1107 N.E. 45th St., Seattle, WA 98105. Single copies and annual subscriptions are sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Prices are: Single copy, $1.00 domestic, $1.30 foreign; annual subscription, $12.00 domestic, $15.00 foreign. Copies of individual articles, in limited numbers, are available from D822, User Services Branch, Environmental Science Information Center, NOAA, Rockville, MD 20852. Departmental news items are not reprinted.

Controlled circulation postage paid at Finance Department, USPS, Washington, DC 20260.

A Comparison of Fish Populations on an Artificial and Natural Reef in the Florida Keys

R. B. STONE, H. L. PRATT,
R. O. PARKER, Jr., and G. E. DAVIS

ABSTRACT—An artificial reef was placed adjacent to a natural coral patch reef of similar size to study the feasibility of increasing fish carrying capacity and total biomass within a given area by augmenting natural reef habitat. After the artificial reef had been in place 7 months, visual observations indicated about equal numbers of fishes and similar species composition on both the artificial reef and the natural patch reef. Although the artificial reef was less than 25 m from the natural reef, it did not diminish the resident populations of the natural reef but doubled the carrying capacity and fish biomass in the immediate vicinity of the two reefs. For the remaining 2 years of this study, the fish populations on both reefs showed similar seasonal fluctuations.

R. B. Stone is with the Office of Marine Recreational Fisheries, NMFS, NOAA, Washington, DC 20235. H. L. Pratt is with the Narragansett Laboratory, Northeast Fisheries Center, NMFS, NOAA, South Ferry Road, Narragansett, RI 02882. R. D. Parker, Jr., is with the Beaufort Laboratory, Southeast Fisheries Center, NMFS, NOAA, Beaufort, NC 28516. G. E. Davis is with the South Florida Research Center, Everglades National Park, P.O. Box 279, Homestead, FL 33030.

Introduction

Various states and local groups are building reefs to develop or improve fishing grounds in response to increasing fishing pressure; however, little effort has been spent on using artificial reefs to expand or rehabilitate natural reef areas. We believe that artificial reefs could be used to effectively expand the amount of reef fish stocks. Ogawa (1973) stated that properly constructed artificial reefs or submarine forests could increase survival, growth levels, and feeding efficiency of certain juvenile fishes. This suggests that building reefs close to other artificial or natural reefs, could be a useful fishery management practice to increase total biomass of reef fishes.

This concept is accepted and has been used successfully by the Japanese (Ogawa, 1973) in their commercial fisheries, but had not been demonstrated for either commercial or recreational fisheries in the United States. Our study was designed to investigate the feasibility of using artificial reefs to increase fish carrying capacity and total biomass within a given area by augmenting natural reef habitat. We also compared the populations of our artificial reef with the fish populations on a nearby natural patch reef to determine if a tire reef is selective for or against any fish species.

Study Area Description

The study area is located northwest of Pacific Reef Light, in Biscayne National Monument, 50 km south of Miami, Fla. (Fig. 1). At lat. 25°22′35″N, it is near the northern limit of living reef corals in North America with annual water temperatures ranging from 16° to 31°C (Vaughn, 1918). This is reflected by low species diversity and small growth forms of hermatypic corals.

The specific area within the Monument that we selected is 274 m northwest of the Pacific Reef Light in 14 m of water. It is a back reef area, a few hundred meters behind the outer barrier ridge, and is subjected to east-west tidal currents. The bottom is coral sand inhabited by a moderate growth of manatee grass, *Syringodium filiforme*, and some turtle grass, *Thalassia testudinium*. The common algae are *Udotea* spp., *Penicillus* spp., and *Rhipocephalus* spp. The area is dotted with coral patch reefs. Except for the depth, these patch reefs are typical of the lagoonal patch reefs described by Hoffmeister (1974) for the entire Florida reef tract. The principal hermatypes are *Montastraea annularis, M. cavernosa, Diploria clivosa, D. labyrinthiformis,* and *Siderastrea siderea*. In the square kilometer we surveyed during the study, there were a dozen distinct reefs ranging from 10 to 30 m in diameter. One of these was chosen as our natural study reef (Fig. 2) and an artificial reef was placed adjacent to it, 21 m to the northwest.

We built the artificial patch reef on 21 January 1972, with 500 automobile tires to approximate the size and relief of the adjacent natural patch reef. Six months after emplacement, the tire reef had slumped and spread from its initial 12 m diameter and 2 m profile to almost a 20 m diameter with only 1 m of vertical relief. A few peripheral tires

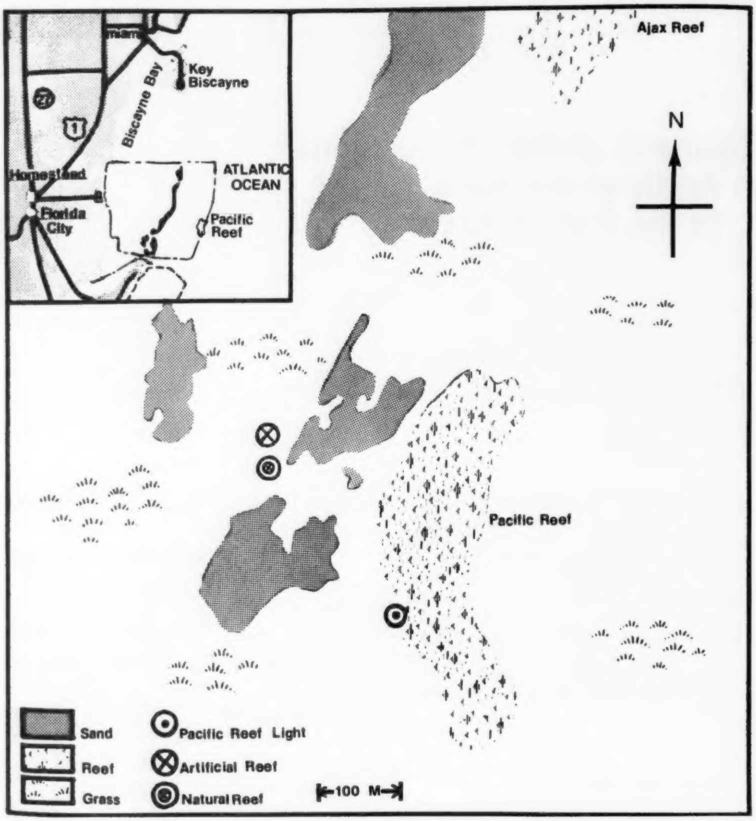


Figure 1.—Pacific Reef study area.

were moved back into the main body of the reef, and it remained stable in that configuration until its removal 24 months later (Fig. 3)

Materials and Methods

We used scrap automobile tires to construct the artificial reef since they are one of the most popular reef building materials in use (Stone, 1975). A 13-mm hole was punched through the tread of each tire to allow air to escape. Then a cylinder of waste concrete (road test core) was levered into the casing opposite the punched hole. We assembled the 500 tires into three different types of units: 250 single-tire units (23-28 cm high), 30 triple-tire units (51-61 cm high), and 20 multi-tire units (7-9 tires high, 1.8 to 2.1 m).

Our observations of fishes on the reefs started immediately following the tire drop. We also trapped and tagged 14 fish on the natural reef the same day. Divers counted fishes on the site the next day for 1 man-hour. Successive counts and observations of fish behavior on both reefs were made from 26 February to 2 March 1972 for 26 man-hours and from 12 to 17 April 1972 for 30 man-hours from an underwater habitat, EDALHAB II (Weeks, 1972). The habitat was located 46 m northwest of the tire reef and allowed teams of three divers to live and work in 14 m of water for up to 5 days. The team members, all from the National Marine Fisheries Service, were Wes Pratt, Narragansett, R.I.; Frank Steimle, Highlands, N.J.; and Clifford Newell, Roger Clifford, and Kenneth Pecci from Woods Hole, Mass. We

Figure 2.—Natural patch reef used for comparison study.

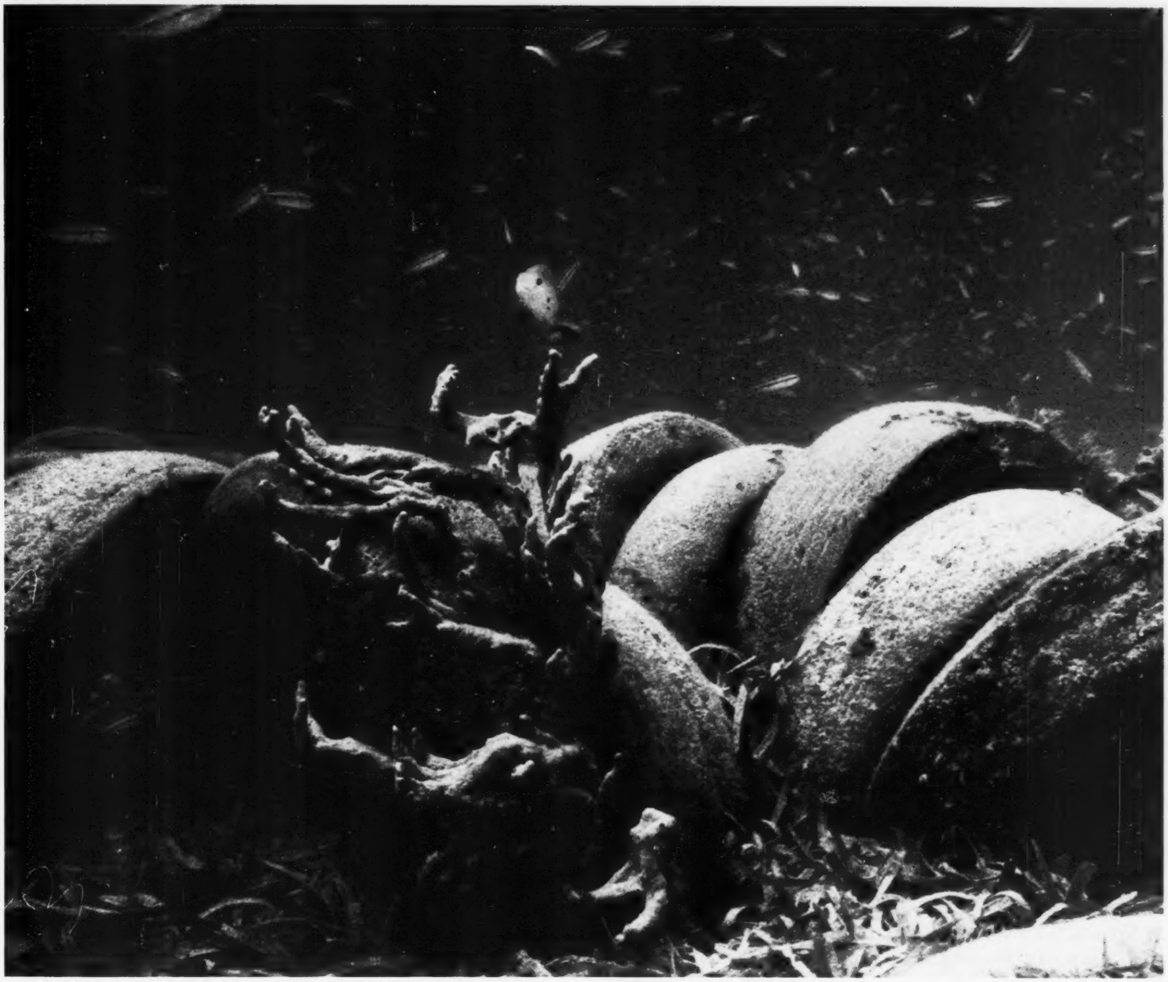


Figure 3.—Artificial reef used for comparison study in its stable configuration as of August 1974.

conducted six seasonal follow-up studies at the site diving from boats over a 28-month period using the same observation techniques developed during the habitat studies.

Seventy independent fish population estimates were made on both reefs. Two or three divers counted fish on each reef from four locations at the edges of the reef (Fig. 4) and then from an area above the reef. This procedure took about an hour for each reef. Both reefs were counted between mid-morning and mid-afternoon and additional, but less regular counts, were made at dawn, dusk, and midnight. Species, number of individuals, mean lengths, and behavioral observations were recorded on waterproof data sheets, held by a clipboard or embedded in fiber glass resin over plywood. We transcribed the information from the data boards onto a matching data form and erased the boards or replaced the data sheets after each count. Lengths of fishes were estimated primarily to separate juveniles from adults.

Several individuals followed us from reef to reef. These and wider ranging fish seen occasionally were considered visitors and distinguished from residents in the data. Approximately 2,000 underwater photographs were taken to aid in species identification and population estimates. The reefs were measured to obtain surface areas for standing crop estimates.

In August 1974, we completed our

Figure 4.—Biologist/diver enumerating fish species on resin.

study by counting both reefs and quantitatively harvesting the fishes on the artificial reef with rotenone. This enabled us to determine the standing crop on the artificial reef and provided a standard with which to evaluate our visual counts on both reefs. After harvesting the fishes, we removed all artificial reef materials from the study site and left the area as it was prior to the construction of the reef.

We encircled the 152.9 m^2 artificial reef, prior to poisoning, with a 26 mm bar mesh seine, 49.2 m long and 6.1 m high, to reduce the chance of fishes escaping the rotenone. On the day of treatment, 21 August 1974, 27 people using 5 boats participated in poisoning the artificial reef, collecting the fishes and removing the reef material. Five liters of Chem Fish Collector[1], the brand of rotenone selected, were divided equally among five 3.8-l squeeze bottles that were then filled with seawater. This provided a concentration of about 4 ppm of 5 percent rotenone on the tire reef. We divided the reef into a pentagon and assigned each section to a diver for treatment and collection of fish. Sections were treated simultaneously from the outside to the center. Four other divers took photographs, herded fish, and helped collect stunned and dead fish. The divers dispersed the rotenone in 5 minutes and finished collecting the dead fish 70 minutes later. The only dead fish observed outside the treated area, during post-poisoning surveys, were small fish that swam through the mesh during treatment and died within 10 m of the net.

The participants cooperating in this study came from the NOAA Atlantic Oceanographic Laboratories in Miami, Fla.; NMFS Laboratories in Beaufort, N.C.; Narragansett, R.I.; Highlands, N.J.; Woods Hole, Mass.; and Miami, Fla.; National Park Service personnel from Biscayne National Monument and Everglades National Park; U.S. Geological Survey personnel from the Fisher Island Station Miami, Fla.; Department of Natural Resources biologists from the States of Georgia and South Carolina; University of Miami graduate students; local contractors; and the Miami Sport Fishing Club. The project was partially supported by the National Oceanic and Atmospheric Administration's Manned Undersea Science and Technology Office as part of their Project FLARE.

Open circuit, self-contained underwater breathing apparatus (scuba) was used in all phases of the study. Diver propulsion vehicles (DPV) were used to survey the surrounding patch reefs but not for the counting excursions.

Results and Discussion

On 22 January 1972, the day after the artificial reef was installed, we finished arranging tires on the reef and made a quick survey of less than 1 hour of both the natural and artificial reef. We observed three species of fish which usually feed near sand bottom or grass beds, hogfish, *Lachnolaimus maximus;* spotted goatfish, *Pseudupeneus maculatus*; and trunkfish, *Lactophrys* sp., foraging in the disturbed sediments around the artificial reef and a school of juvenile fish using the tires for shelter that appeared to be grunts, *Haemulon* sp., but were too small for positive identification. During the limited time available, about 250 individuals of 24 species were seen or photographed on the natural reef with the pomadasyids and the labrids accounting for most of the fishes. Obviously overlooked were the more secretive fishes such as the cardinal fishes, Apogonidae.

The first extensive survey of both reefs started on 26 February 1972, 37 days after establishing the artificial reef. The EDALHAB II habitat was deployed on the study site and three biologists spent 4.5 days in the habitat, each averaging 6 hours a day working on the reefs. We found 128 individuals of 28 species residing on the artificial reef. Most of the fishes were juveniles or subadults.

Young tomtates, *Haemulon aurolineatum*, and French grunts, *H. flavolineatum*, accounted for over half of the individuals. The young tomtates swam in schools slightly above the artificial reef and would retreat to the shelter of the tires when approached. The French grunts stayed near the bottom of the reef, much closer to the reef material than the tomtates. Other species occurring in abundance on the

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

artificial reef were parrotfishes, including *Scarus taeniopterus*, *Sparisoma viride*, and *S. aurofrenatum*, surgeonfish, and goatfishes. The rest of the fishes occurred as one or two individuals of each species (Table 1). Several of these were juvenile fishes, spotfin butterfly fish, *Chaetodon ocellatus*; highhat, *Equetus acuminatus*; jackknifefish, *E. lanceolatus*; and the bicolor damselfish, *Pomacentrus partitus*, which had apparently established territories on the new habitat created by the artificial reef.

The natural reef contained 387 individuals of 37 species (Fig. 2). The species composition was similar with tomtates most numerous; however, the natural reef did have more species of pomacentrids and greater numbers of both pomacentrids and pomadasyids.

On 12 April 1972, the habitat was repositioned near the study area. Although a few tires had "bedded" into the sand, the position of the reef material was virtually unchanged. The population of the tire reef had increased to 573 individuals of 53 species (Fig. 5). A number of motile invertebrates were seen on the artificial reef in April including two spiny lobsters, *Panulirus argus*. The natural patch reef community included 866 individuals of 58 species of fish (Fig. 5).

The dominant species on both reefs was the tomtate with about 300 occurring on the natural reef and about 70 on the artificial reef. The difference in the number of individuals between the two reefs is largely attributable to greater numbers of tomtates, bicolor damselfish, and bluehead wrasse on the natural reef (Table 1).

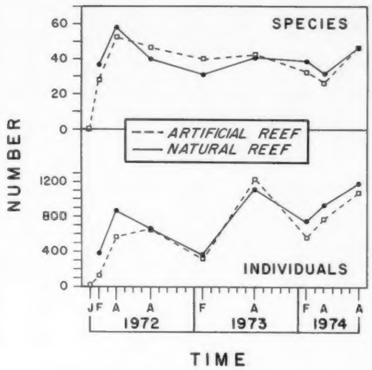


Figure 5.—Occurrence of fish species and individuals on the artificial and natural reef by date.

The new artificial reef continued to be attractive to juvenile fishes, probably because of reduced competition for unclaimed territories. Species diversity equaled that of the natural reef by April (Fig. 5). Two 2.5-cm bicolor damselfish had established territories on tires and three 5-cm yellowhead wrasse, *Halichoeres garnoti*, were associated with a juvenile doctorfish, *Acanthurus chirurgus*, and several unidentified juveniles on an outlaying single tire unit. A juvenile French angelfish, *Pomacanthus paru*, took up residence in an upright single tire and a juvenile jackknife-fish was seen inside the same tire in which it was observed during the February mission. Assuming it was the same fish, it had grown about 1.5 cm.

Large (72-cm) rainbow parrotfish, *Scarus guacamaia*, used the multitire units and the natural study reef for shelter at night. Two or three were

Table 1.—Comparison of populations by reef and sampling date.

	Artificial reef										Natural reef								
	1972			1973		1974					1972			1973		1974			
Species	Feb.	Apr.	Aug.	Feb.	Aug.	Feb.	Apr.	Aug.	Rote-none	Status[1]	Feb.	Apr.	Aug.	Feb.	Aug.	Feb.	Apr.	Aug.	Status
Acanthuridae																			
Acanthurus bahianus	0	4	6	6	8	7	8	6	10	DR	0	3	1	4	2	7	3	2	DR
A. chirurgus	4	5	5	P	0	0	0	3	2	DR	3	4	4	0	0	0	0	3	DR
A. coeruleus	0	0	7	0	0	0	0	4	2	DR	0	1	2	0	0	0	6	4	DR
Antennariidae																			
Antennarius multiocellatus	0	0	0	0	0	0	0	0	1	C									
Apogonidae																			
Apogon binotatus	3	10	0	P	0	0	0	0	2	NR	15	10	4	5	6	2	0	7	NR
A. maculatus	2	20	2	0	1	0	0	6	0	NR	10	9	4	2	13	1	0	1	NR
A. pseudomaculatus	0	0	0	0	0	0	0	0	53	NR	0	0	0	0	0	0	0	0	—
A. quadrisquamatus	0	1	0	0	0	0	0	0	0	NR	0	0	0	0	0	0	0	0	—
Phaeoptyx pigmentaria	0	0	0	0	0	0	0	0	9	NR	0	0	0	0	0	0	0	0	—
Atherinidae																			
Allanetta harringtonensis	0	0	0	0	0	0	0	1	0	D	0	0	0	0	0	0	0	100	D
Aulostomidae																			
Aulostomus maculatus	0	0	0	0	0	0	0	0	0	—	0	1	0	0	0	0	0	0	DV
Balistidae																			
Aluterus schoepfi	0	2	1	0	0	0	0	0	2	DV	1	0	0	0	0	0	0	0	DV
A. scriptus	0	1	0	P	0	0	0	0	0	DV	0	1	0	P	0	0	0	0	DV
Monacanthus ciliatus	0	0	0	0	0	0	0	0	0	—	0	4	0	0	0	0	0	1	DR

Continued on next page.

Table 1.—Continued.

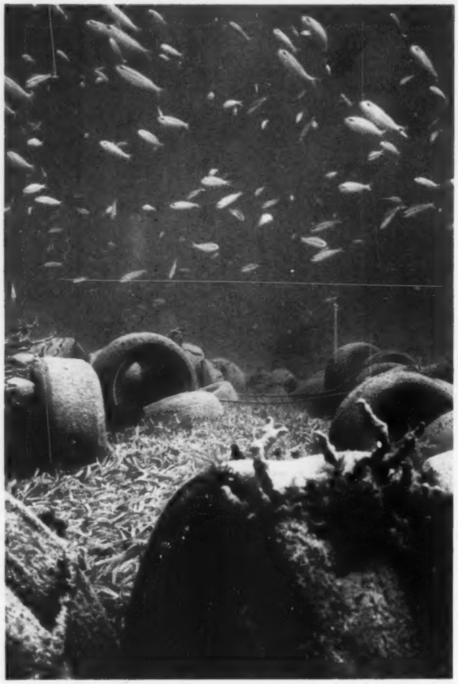
Species	Artificial reef 1972 Feb.	Apr.	Aug.	1973 Feb.	Aug.	1974 Feb.	Apr.	Aug.	Rote-none	Status[1]	Natural reef 1972 Feb.	Apr.	Aug.	1973 Feb.	Aug.	1974 Feb.	Apr.	Aug.	Status
Bothidae																			
Syacium micrurum	0	0	0	0	0	0	0	0	1	C	0	0	0	0	0	0	0	0	—
Carangidae																			
Caranx bartholomaei	0	2	0	1	2	0	0	0	0	DV	0	2	0	0	0	0	0	13	DV
C. crysos		0	0	0	0	0	0	0	1	DV	0	0	0	0	0	0	0	0	—
C. ruber	7	7	7	3	3	14	7	13	0	DV	7	6	4	2	7	4	10	10	DV
Unidentified	0	0	7	0	0	0	0	0	0	?	0	0	12	0	0	0	0	0	?
Chaetodontidae																			
Chaetodon ocellatus	2	1	0	P	0	0	2	2	2	DR	0	2	0	P	0	0	2	2	DR
C. sedentarius	0	4	2	0	0	0	0	0	0	DR	0	1	3	0	0	0	0	0	DR
Holacanthus bermudensis	0	0	0	0	0	0	0	0	0	—	1	0	1	0	0	0	0	0	DV
H. ciliaris	0	0	0	P	1	1	1	0	1	DR	2	4	2	0	1	1	1	0	DR
H. tricolor	0	0	0	0	0	0	0	0	0	—	0	0	1	1	1	1	1	2	DR
Pomacanthus arcuatus	0	2	0	0	2	1	1	1	0	DV	0	2	0	0	2	0	2	1	DV
P. paru	0	1	0	0	0	0	0	2	0	DR	1	1	0	0	0	0	0	2	DR
Cirrhitidae																			
Amblycirrhitus pinos	0	0	0	0	0	0	0	0	0	—	1	1	0	0	0	0	0	0	DRC
Dasyatidae																			
Urolophus jamaicensis	0	0	0	0	0	0	0	0	0	—	0	1	0	0	0	0	0	0	DV
Gobiidae																			
Coryphopterus dicrus	0	0	0	0	0	0	0	0	1	C	0	0	0	0	0	0	0	0	—
C. glaucofraenum	0	300	0	P	225	P	P	300	90	DR	35	100	P	0	P	P	P	300	DR
C. hyalinus	0	0	0	P	1	P	0	50	0	DC	0	20	0	0	75	P	0	65	DC
Gnatholepis thompsoni	0	0	0	0	0	0	0	4	0	DR	0	0	0	0	0	0	0	8	DR
Gobiosoma evelynae	0	25	0	0	0	0	0	0	0	DC	0	0	0	0	0	0	0	0	—
G. oceanops	0	1	0	P	2	P	0	1	0	DR	2	1	2	0	4	P	P	6	DR
Ioglossus helenae	0	0	0	0	0	0	0	2	0	DR	2	3	0	0	0	0	0	0	DR
Gerreidae																			
Eucinostomus gula	0	4	0	0	0	0	0	0	0	NV	0	0	0	0	0	0	0	0	—
Holocentridae																			
Unidentified	0	0	0	0	0	0	0	0	1	C	0	0	0	0	0	0	0	0	—
Labridae																			
Halichoeres bivittatus	0	0	36	48	44	22	15	25	39	DR	0	0	18	8	15	11	7	25	DR
H. garnoti	1	3	2	5	4	4	4	20	2	DR	0	6	8	6	5	6	3	15	DR
H. maculipinna	2	2	18	16	7	4	3	3	2	DR	10	53	10	5	4	5	2	2	DR
H. Pictus	0	14	1	0	0	1	0	0	0	DR	0	0	0	0	0	0	0	0	—
H. poeyi	0	0	1	0	1	1	1	0	0	DR	0	0	2	0	2	1	0	0	DR
Hemipteronotus splendens	0	2	0	0	0	0	0	0	0	C	0	0	0	0	0	0	0	0	—
Lachnolaimus maximus	1	3	2	1	1	0	0	2	0	DR	2	4	1	2	2	1	3	1	DR
Thalassoma bifasciatum	2	3	13	10	19	15	11	11	9	DR	25	116	9	19	20	35	10	12	DR
Unidentified	0	7	12	4	0	0	0	0	1	?	0	0	0	2	0	0	0	0	—
Lutjanidae																			
Lutjanus analis	0	0	0	1	0	0	0	0	0	DV	0	0	0	1	1	1	1	0	DV
L. buccanella	0	0	17	2	1	1	0	11	10	R	0	0	15	2	0	0	0	0	R
L. griseus	1	0	0	0	0	0	0	0	0	DV	0	0	0	0	0	0	0	0	—
L. mahogoni	0	1	0	0	0	0	0	1	0	DV	0	1	0	0	0	0	0	1	DV
L. synagris	0	0	0	0	0	0	0	0	0	—	1	0	0	0	0	0	0	0	DV
Ocyurus chrysurus	0	1	2	0	1	0	0	0	0	DV	0	3	1	0	1	4	0	0	DV
Unidentified	0	0	0	0	5	0	0	0	0	?	0	0	0	0	10	0	0	0	?
Mullidae																			
Mulloidichthys martinicus	0	0	1	0	2	2	1	0	0	D	0	0	1	0	1	0	0	0	D
Pseudupeneus maculatus	3	4	16	9	7	3	3	6	8	DNV	7	4	8	6	1	2	3	5	DNV
Muraenidae																			
Gymnothorax moringa	0	1	0	0	0	0	0	1	0	DNR	1	2	0	0	1	1	0	0	DNR
Opistognathidae																			
Unidentified	0	0	1	0	0	2	1	0	0	?	0	0	1	0	0	0	0	0	?
Ostraciidae																			
Lactophrys triqueter	0	1	1	1	0	1	2	1	0	DV	1	1	1	1	0	1	1	1	DV
Pempheridae																			
Pempheris schomburgki	0	1	0	0	0	0	0	0	0	DV	0	0	0	0	0	0	0	0	—
Pomacentridae																			
Chromis cyaneus	0	0	1	0	2	1	0	0	1	DR	0	1	6	4	29	5	1	8	DR
C. insolatus	0	0	0	0	0	0	0	0	0	—	1	3	0	0	0	0	0	0	DR
Microspathodon chrysurus	0	0	0	0	0	0	0	0	0	—	0	1	3	0	0	0	6	5	DR

Continued on next page.

Table 1.—Continued.

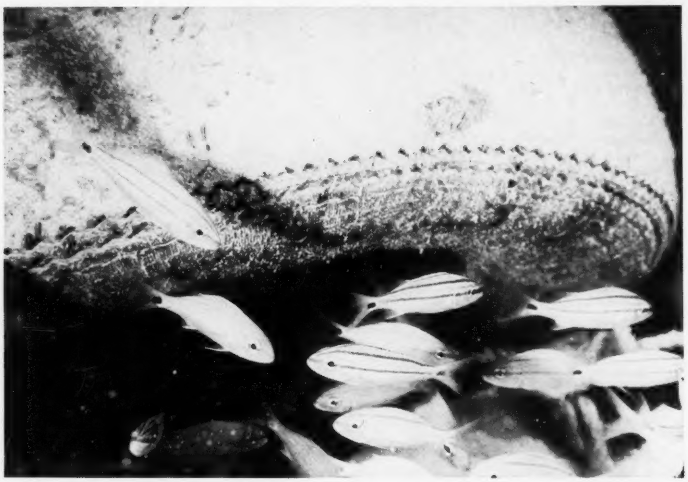
Species	Artificial reef 1972 Feb.	Apr.	Aug.	1973 Feb.	Aug.	1974 Feb.	Apr.	Aug.	Rote-none	Status[1]	Natural reef 1972 Feb.	Apr.	Aug.	1973 Feb.	Aug.	1974 Feb.	Apr.	Aug.	Status
Pomacentrus fuscus	0	1	2	2	0	0	0	1	3	DR	0	3	10	P	0	0	0	3	DR
P. partitus	1	2	1	P	3	0	0	15	3	DR	48	80	18	47	31	18	12	50	DR
P. planifrons	2	1	0	2	0	1	0	1	0	DR	32	5	2	7	5	2	1	4	DR
P. variabilis	1	2	2	6	4	2	2	2	1	DR	3	2	6	10	6	8	2	6	DR
Priacanthidae																			
Priacanthus arenatus	0	0	0	0	0	0	0	0	0	—	0	1	0	0	0	0	0	0	NV
Pomadasyidae																			
Anisotremus virginicus	0	1	1	1	1	0	0	0	1	DNV	0	1	0	0	0	0	0	0	DNV
Haemulon album	0	0	0	0	2	3	3	1	0	D	0	0	0	0	0	3	1	1	D
H. aurolineatum	50	73	450	100	805	400	675	500	760	DNR	100	312	500	220	800	453	725	400	DNR
H. carbonarium	0	0	0	0	1	0	0	0	0	D	0	0	0	0	0	0	0	0	—
H. chrysargyreum	0	1	2	0	1	0	0	0	0	D	0	3	1	0	1	4	0	0	D
H. flavolineatum	25	26	7	73	7	42	15	14	4	DNR	25	35	0	P	16	151	113	50	DNR
H. melanurum	0	0	1	1	0	0	0	1	2	D	0	0	1	0	0	3	0	0	D
H. plumieri	2	1	2	3	1	15	5	0	2	DNR	3	1	0	2	1	4	0	0	DR
H. sciurus	1	2	3	0	1	0	0	0	0	DR	2	5	0	0	0	0	0	0	DR
H. striatum	0	0	0	0	0	0	0	0	412	DR	0	0	0	0	0	0	0	1	DR
Unidentified	0	0	0	0	0	0	0	0	2	?	0	0	0	0	0	0	0	0	—
Scaridae																			
Scarus coeruleus	0	2	0	0	0	0	0	2	0	DV	0	1	0	0	0	0	0	0	DV
S. croicensis	0	0	1	4	17	5	6	1	1	D	0	0	0	1	12	5	3	0	D
S. guacamaia	0	4	0	0	0	0	0	0	0	NV	2	2	0	0	0	0	0	0	NV
S. taeniopterus	2	7	5	11	10	2	0	5	0	DR	4	4	6	3	8	0	0	6	DR
Sparisoma aurofrenatum	3	2	5	3	0	1	1	6	2	DR	2	8	3	4	0	3	1	6	DR
S. chrysopterum	0	0	0	0	3	2	1	0	0	D	0	0	0	0	2	0	3	0	D
S. radians	0	0	0	0	0	0	0	25	0	D	0	0	0	0	0	0	0	25	D
S. rubripinne	0	0	0	0	0	0	0	2	4	D	0	0	0	0	0	0	0	12	D
S. viride	4	1	1	0	0	0	0	1	1	D	10	3	2	0	0	1	1	1	D
Unidentified	0	0	0	0	0	0	0	0	10	?	0	0	0	0	0	0	0	0	—
Sciaenidae																			
Equetus acuminatus	1	0	1	1	0	0	0	0	0	D	0	0	0	0	0	0	0	0	—
E. lanceolatus	1	1	0	0	0	0	0	1	0	DR	0	0	0	0	0	0	0	0	—
Odontoscion dentex	0	1	0	0	0	0	0	0	0	NV	0	1	0	0	0	0	0	0	NV
Scombridae																			
Scomberomorus cavalla	0	0	0	0	1	0	0	0	0	DV	0	0	0	0	0	0	0	0	—
S. maculatus	0	0	1	0	0	0	0	0	0	DV	0	0	0	0	1	0	0	0	DV
Scorpaenidae																			
Scorpaena plumieri	0	0	0	0	0	0	0	0	0	—	0	0	0	0	0	0	0	1	D
Serranidae																			
Epinephelus morio	0	0	0	0	0	0	0	1	0	D	0	0	0	0	0	0	0	1	D
E. striatus	0	0	0	0	0	0	0	0	0	—	0	0	0	0	1	0	0	0	D
Hypoplectrus indigo	0	0	0	0	1	1	0	0	0	D	0	0	0	0	4	1	0	0	D
H. nigricans	0	0	2	0	0	0	0	0	0	D	0	0	0	0	0	0	0	0	—
H. puella	0	2	3	5	2	0	0	0	0	DR	0	2	0	0	1	0	0	0	DR
H. unicolor	1	3	0	1	3	1	1	3	2	DR	3	1	0	0	1	1	0	0	DR
Petrometopon cruentatum	0	0	4	2	4	1	2	3	6	DR	1	2	2	2	2	2	2	4	DR
Serranus baldwini	0	0	0	0	0	0	0	0	1	D	0	0	0	0	0	0	0	0	—
S. tabacarius	0	0	0	0	1	0	0	1	0	D	0	0	0	0	0	0	0	0	—
S. tigrinus	0	0	2	3	2	1	2	5	5	DR	2	1	0	0	3	3	2	3	DR
Sparidae																			
Calamus calamus	2	2	1	1	0	0	0	1	0	DV	0	3	0	1	0	1	1	2	DV
Sphyraenidae																			
Sphyraena barracuda	0	0	1	0	2	0	0	0	0	DV	0	0	0	0	0	0	0	0	—
Synodontidae																			
Synodus foetens	1	1	0	0	0	0	0	0	0	DR	1	1	0	0	0	0	0	0	DR
S. synodus	1	2	1	0	0	0	0	0	4	DR	1	2	1	0	0	0	0	0	DR
Tetraodontidae																			
Canthigaster rostrata	2	2	3	8	6	6	3	10	17	DR	20	15	3	9	10	4	4	8	DR
Xenocongridae																			
Chilorhinus suensoni	0	0	0	0	0	0	0	0	2	C	0	0	0	0	0	0	0	0	—
Total																			
Individuals	128	573	663	334	1,217	563	776	1,078	1,495		387	866	679	376	1,108	756	933	1,186	
Species	28	53	47	40	43	34	27	47	45		37	58	40	31	41	39	33	46	DR
Summary	Total: 98 species										Total: 85 species								

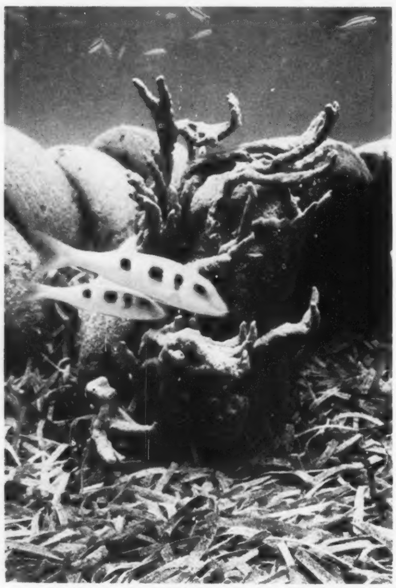
[1]D=diurnal, N=nocturnal, R=resident, V=visitor, P=present, 0=no information or absent, C=cryptic.



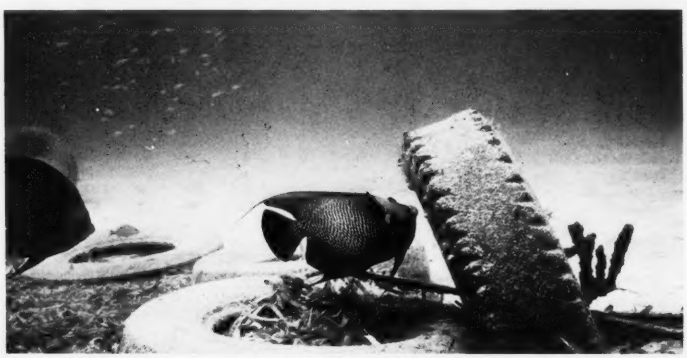
General views of the tire reef, above and top right.

Two goatfish swim past sponge and tires.





Tomtates on the tire reef (above). Below, a French angel feeds at a tire on the study reef.



discovered every night lying quietly, practically filling the tire's center with their bulk, while cleaner shrimp picked over their scales. During the day, a group of five or six of these giants could be seen from a distance grazing the surrounding grass beds.

We conducted the rest of the surveys without the EDALHAB II habitat using scuba gear from surface vessels. Our August 1972 comparisons of the two study reefs revealed about equal numbers of fishes on each reef but greater species diversity on the tire reef in daylight hours (Fig. 5). The greater species diversity on the artificial reef was a result of pelagic visitors. There were 663 individuals of 47 species on the 7-month-old artificial reef and 679 individuals of 40 species on the natural patch reef (Fig. 5).

The increase in the number of fishes on the artificial reef was attributed to the presence of about 450 juvenile grunts (probably tomtates) less than 5 cm long. There were about equal numbers of the same size juveniles on the natural study reef. The subadult tomtates (about 10 cm) that had been present on both reefs in April had disappeared on the natural reef and all but eight (about 15 cm) were absent from the artificial reef.

The disappearance of the tomtates greater than 10 cm in length seems to indicate a change in habitat requirements. This agrees with the findings of Sokolova (1969). In his study of the commercial trawl fishery of the Campeche Bank, he found tomtates from 9 to 23 cm long, with predominant lengths from 17 to 19 cm, occurring in the catches. Since there were no tomtates less than 9 cm being caught, Sokolova believed that the younger age groups inhabit different areas and remain separate from the adults.

We observed a small school of juvenile blackfin snapper, *Lutjanus buccanella*, on the tire reef during the August mission. Although the adults are normally caught in water deeper than 50 m, juveniles have been seen occasionally by divers in shallower water. Stark and Davis (1966) described a 14.6-cm specimen speared west of Cat Cay, Great Bahama Bank, at a depth of 12 m.

Based on the results of the February 1972 mission, we anticipated a seasonal decline in the number of species and individuals observed on both study reefs during our February 1973 mission. This did occur with 40 species and 334 individuals counted on the artificial reef and 376 individuals of 31 species observed on the natural reef. The dominant species on both reefs were grunts, tomtate, and French grunts on the artificial reef, and tomtate on the natural reef.

The number of individuals increased considerably by our August 1973 survey (Fig. 5). Again, most of this increase was caused by the presence of juvenile grunts. We observed about 800 juveniles, predominantly tomtates, on each of the study reefs. The wrasses were next in abundance on the artificial reef with 76 individuals of 6 species and the damselfishes were second in abundance on the natural reef (Table 1).

Our counts of individuals on the study reefs were higher during the February 1974 survey than previous February missions (Fig. 5). This was attributable to the large number of subadult tomtates that remained from the influx of juveniles on both reefs prior to the August 1973 mission. We found subadult French grunts to be second in abundance on both reefs followed by bluehead wrasse on the natural reef and slippery dick, *Halichoeres bivittatus*, on the artificial reef (Table 1).

Tomtates remained the dominant species on both reefs in the April 1974 survey, but there was a difference in the size of the juvenile tomtates. The juveniles occurring on the artificial reef were about 2 cm long, while the juveniles on the natural reef were from 3.5 to 6 cm long. This may be common with juvenile tomtates. The adults are reported to spawn over a prolonged period (Sokolova, 1969) and juveniles have been observed throughout the year (Munro et al, 1973). Sokolova (1969) stated that the extended spawning period probably causes a variety of sizes within the same age groups.

Due to rough seas, we were limited to one brief count in April 1974. This probably accounts for the low number of species observed during this mission (Fig. 5).

The August 1974 mission terminated the field portion of this study. We counted both reefs and collected all the fishes on the artificial reef using rotenone. The rotenone sample consisted of 1,495 individuals of 45 species with a total weight of 10.4 kg (Table 2). Our visual estimates of fishes on the artificial reef indicated 1,078 individuals of 47 species present. The difference in the visual counts and the actual number of fishes collected was caused mainly by an underestimation of the number of juvenile grunts present on the reef.

The visual counts on the artificial and natural reefs from August 1972 through the completion of the study showed similar numbers of individuals and species living on each reef (Fig. 5). One exception that occurred throughout the study was the consistent presence of blue chromis, *Chromis cyaneus*, on the upper portion of the natural reef and only occasional occurrence on the artificial reef (Table 1). Since the blue chromis is a plankton feeder, picking individual zooplankters out of the water passing or upwelling over the reef, it frequently occurs in loose aggregations just above reefs (Bohlke and Chaplin, 1968; Randall, 1968). The higher vertical profile of the natural patch reef caused a visible upwelling effect of the current which was absent on the tire reef. This probably provided conditions better suited for blue chromis than the lower profile artificial reef.

Cleaning Stations

By 1974 the artificial reef had matured to the stage of supporting several fish cleaning stations. A juvenile French angelfish cleaned bar jacks, *Caranx ruber*. A banded coral shrimp, *Stenopus hispidus*, cleaned resident graysbys, *Petrometopon cruentatum*, and a transient red grouper, *Epinephelus morio*, from inside the casing of a tire.

During repeated observations in February and April 1972, we observed coral shrimp cleaning rainbow parrotfish at night on both reefs. Neon gobys, *Gobiosoma oceanops*, maintained a

Table 2.—Fishes collected from FLARE artificial reef at Pacific Reef study site.

Species	No.	Length (mm)	Wt. (g)
Acanthuridae			
Acanthurus bahianus	10	177-249	1,675
A. chirurgus	2	210-235	439
A. coeruleus	2	240-248	549
Antennariidae			
Antennarius multiocellatus	1	51	15
Apogonidae			
Apogon binotatus	2	42-48	3
A. pseudomaculatus	53	25-61	75
Phaeoptyx pigmentaria	9		15
Balistidae			
Aluterus schoepfi	2	355-365	825
Bothidae			
Syacium micrurum	1	123	15
Carangidae			
Caranx crysos	1	565	494
Chaetodontidae			
Chaetodon ocellatus	2	137-149	175
Holacanthus ciliaris	1		5
Gobiidae			
Coryphopterus glaucofraenum	90	31-73	89
C. dicrus	1	36	1
Holocentridae			
Unidentified	1	54	5
Labridae			
Halichoeres bivittatus	39	29-87	80
H. garnoti	2	53-56	10
H. maculipinna	2	65-72	15
Thalassoma bifasciatum	9	30-87	25
Unknown	1	68	6
Lutjanidae			
Lutjanus buccanella	10	27-95	25
Mullidae			
Pseudupeneus maculatus	8	114-162	275
Pomacentridae			
Pomacentrus fuscus	3	32-69	20
P. partitus	3	76-106	73
P. variabilis	1	86	15
Chromis cyaneus	1	97	20
Pomadasyidae			
Anisotremus virginicus	1	287	491
Haemulon aurolineatum	760	17-170	1,000
H. flavolineatum	4	109-155	175
H. melanurum	2	55-59	10
H. plumieri	2	217-277	510
H. striatum	410	30-70	875
H. striatum	2	218-250	375
Unidentified	2		10
Scaridae			
Sparisoma rubripinne	4	131-193	312
S. viride	1	88	13
S. aurofrenatum	2	97-225	240
Scarus croicensis	1	125	37
Unidentified	10		53
Serranidae			
Petrometopon cruentatum	6	157-302	1,181
Serranus tigrinus	5	46-88	25
S. baldwini	1	35	1
Hypoplectrus unicolor	2	58-73	15
Synodontidae			
Synodus synodus	4	91-133	50
Tetraodontidae			
Canthigaster rostrata	17	33-71	75
Xenocongridae			
Chilorhunus suensoni	2	109-124	8

Total specimens=1,495 Total species=45
Total weight=10,400 g

characteristic station on a patch of brain coral, *Diploria labyrinthiformis*, and cleaned smooth trunkfish, *Lactophrys triqueter*, acanthurids, and serranids. Bar jacks were cleaned daily, every few hours, by a juvenile French angelfish and on nearby patch reefs by Spanish hogfish, *Bodianus rufus*.

Visual Counts and the Rotenone Collection

The basis for our comparison study is the ability of biologist/divers to identify and enumerate the fish populations on the two study reefs. This ability was supplemented by the extensive use of underwater photography to later confirm many identifications and, in a few cases, aid in the counts. The validity of diver estimates of fish populations was tested in August 1974 when the reef was poisoned with rotenone prior to removing the tire units from Biscayne National Monument. This operation revealed shortcomings and advantages in both techniques.

Visual counts by divers permit an uninterrupted analysis of seasonal flux and reef maturity. The fish best documented by this method are the larger and more obvious reef fishes, primarily herbivores and plankton feeders with a few opportunistic carnivores also being relatively easy to count. These fish include the acanthurids, chaetodontids, labrids, pomacentrids, pomadasyids, scarids, and some serranids. In addition, after many hours of quiet observation, we documented a population of itinerants which made rounds that included one or both of the study reefs on a daily basis. They were usually predatory species; however, the most frequently observed activity was a visit to a cleaning station. Carangids and lutjanids composed most of this group. The third group observed was the smaller or more secretive fishes. These include many diverse families with a small combined biomass. The apogonids and gobiids are the most numerous.

The rotenone method has the distinct advantage of providing an actual sample of fish which can be physically examined, counted, and identified. Its major shortcoming is that no matter how careful the investigator, some fish, notably transients like lutjanids and carangids and a few residents, flee the introduction of the poison. Others, such as the hovering goby, *Ioglossus helenae*, retreated into the sand to die, and were missed by the samplers. The loss of transients is lamentable, but does not significantly affect the standing crop estimates of the reef.

Specific comparisons of major families counted and collected in August 1974 reveal that the biologist/diver performs well as a sampler. Divers were very close in the estimate of acanthurids on the reef. They severely underestimated the apogonids, but since this is a nocturnal species, a night count would have been more successful as it was in April 1972. The school of visiting bar jacks counted by the divers avoided the poisoning of the reef. By snorkling above the reef, we discovered that some transients avoid tank divers. Resident chaetondonts and labrids compared fairly well. The larger gray angelfish, *Pomacanthus arcuatus*, and the hogfish, *Lachnolaimus maximum*, disappeared from the reef prior to the introduction of rotenone. Adult lutjanids were absent from the sample; 10 of the 11 juvenile blackfin snappers reported by divers, were collected successfully. Samples of mullids, pomacentrids, and serranids compared well.

The largest counting error involved the pomadasyids. Four hundred and twelve striped grunt, *Haemulon striatum*, were mixed with the school of 760 tomtates. In the limited time available for counts, the divers incorrectly assessed the juvenile grunts as all tomtates and then concentrated on enumerating less obvious species on the tire reef.

The composition of the rotenone sample indicates that a biologist/diver can make a fair estimate of a reef population if given enough bottom time. Identification of dominant fish species was unexpectedly accurate. Trained divers could assess seasonal flux, the role of itinerant fish, presence of cleaning stations, and the presence of a few cryptic fish that even a careful rotenone sample could not provide.

Biomass Estimates

The 10.4 kg of fishes collected from the artificial reef represented a stand-

ing crop of 680 kg/hectare. This is high compared with standing crop estimates of reef fishes on several natural reefs, but low compared with most fish biomass estimates on artificial reefs in tropical and subtropical areas (Table 3).

Although our biomass estimates appeared low compared with other artificial reef values, we estimated that the biomass values on this artificial reef approximated those of the adjacent natural patch reef. We were not able to poison the natural reef; however, through visual observations we determined that the surface areas of the two reefs and the numbers and sizes of the fishes on them were similar.

Other investigators (Randall, 1963; Wass, 1967; and McVey, 1970) have observed that fish populations are higher when rough bottom habitat is isolated from natural reef habitat. Randall (1963) attributed the much larger fish biomass per unit of area on a small artificial reef off St. John (Table 3) to the availability of additional food sources in the grass beds surrounding the reef.

Our artificial reef doubled the carrying capacity and reef fish biomass in the immediate vicinity of the natural patch reef.

Although the artificial reef was less than 25 m from the natural reef, it did not diminish the resident population of the natural reef by attracting them to the new habitat. Most of the resident species on the patch reef were recruited to the artificial reef as juveniles. Adult itinerant fishes started using the shelter the new reef afforded as soon as it was constructed. The fish biomass on the artificial reef increased through the first 7 months. Then in August 1972, the population estimates on both the natural and artificial reefs revealed about equal numbers of fishes on both reefs (Fig. 5) and similar species composition. From August 1972 through the completion of the study in August 1974, the fish populations on both reefs showed similar seasonal fluctuations.

A well planned and constructed artificial reef is a mutually beneficial enterprise for both fish and man. The construction of a reef or fish haven can change a barren, relatively unproductive substrate into a dynamic, highly productive environment. Increasing the amount of rough bottom habitat provides immediate shelter and subsequent food for a complex of organisms which may have been otherwise lost to the biota. The results of this study indicate that artificial reefs also can be used to augment productive natural reef and rough bottom areas and increase total biomass within a given area without detracting from biomass potential in other areas.

Table 3.—Comparison of fish biomass on tropical and subtropical reefs.

Reference	Location	Lb per acre	Kg per hectare
	Natural reefs		
Randall, 1963	Virgin Islands	1,420	1,590
Wass, 1967	Kaneohe Bay, Oahu	1,120	1,250
Bardach, 1959	Bermuda	440	490
Odum and Odum, 1955	Eniwetok Atoll	400	450
Brock, 1954	Average of 9 Hawaiian areas	320	360
Fast, 1974	S.W. Puerto Rico	244	270
	Average	657	735
	Artificial reefs		
Randall, 1963	Virgin Isl. (concrete blocks)	[1]6,230	[1]6,980
McVey, 1970	Pokai Artificial Reef (concrete pipes) Avg. of 16 censuses	2,340	2,620
Fast, 1974	Puerto Rico (Tires)	1,946	2,180
Morris, 1965	Pokai Artificial Reef (car bodies)	1,480	1,660
	Maunalua Bay, Oahu (car bodies)	900	1,010
Stone et al. 1979 (present study)	Florida Keys (Tires)	607	680
Morris, 1965	Keawakapu, Maui (car bodies)	230	260
	Average	1,962	2,199

[1]Figure based on roughly circular area of 125 m^2 containing interconnecting blocks and not actual area of blocks.

Literature Cited

Bardach, J. E. 1959. The summer standing crop of fish on a shallow Bermuda reef. Limnol. Oceanogr. 4:77-85.

Bohlke, J. E., and C. C. G. Chaplin. 1968. Fishes of the Bahamas and adjacent tropical waters. Livingston Publ. Co., Wynnewood, Pa., 771 p.

Brock, V. E. 1954. A preliminary report on a method of estimating reef fish populations. J. Wildl. Manage. 18:297-308.

Fast, D. E. 1974. Comparative studies of fish species and their populations on artificial and natural reefs off southwestern Puerto Rico. M. S. Thesis, Univ. Puerto Rico, Mayaguez, 90 p.

Hoffmeister, J. E. 1974. Land from the sea. The geologic story of south Florida. Univ. Miami Press, Coral Gables, 143 p.

McVey, J. P. 1970. Fishery ecology of the Pokai artificial reef. Ph.D. Thesis, Univ. Hawaii, Honolulu, 268 p.

Morris, D. E. 1965. Sea sled and SCUBA reconnaissance of inshore areas and studies on effects of artificial shelters on standing crops of fishes. Proj. No. F-5-R-13. Job No. 13. Fish and Game, Honolulu, Hawaii, 7 p.

Munro, J. L., V. C. Gaut, R. Thompson, and P. H. Reeson. 1973. The spawning seasons of Caribbean reef fishes. J. Fish Biol. 5:69-84.

Odum, H. T., and E. P. Odum. 1955. Trophic structure and productivity of a windward coral reef community on Eniwetok Atoll. Ecol. Monogr. 25:291-320.

Ogawa, R. 1973. Various biological questions regarding artificial reefs. Ocean Age 3:21-30.

Randall, J. E. 1963. An analysis of the fish populations of artificial and natural reefs in the Virgin Islands. Caribb. J. Sci. 3:31-47.

________. 1968. Caribbean reef fishes. T. F. H., Jersey City, 318 p.

Sokolova, L. V. 1965. Distribution and biological characteristics of the main commercial fish of Campeche Bank. *In* A. S. Bogdanov (editor), Soviet-Cuban fishery research, p. 208-224. Israel program for scientific translations, Jerusalem. (Avail. U.S. Dep. Commer., CFSTI, Springfield, VA. 22151, as TT69-59016.)

Stark, W. A., II, and W. P. Davis. 1966. Night habits of fishes of Alligator Reef, Florida. Ichthyol. Aquarium J. 38:313-356.

Stone, R. B. 1975. Scrap tires and fishery resources. *In* F. A. Ayer (compiler), Environmental aspects of chemical use in rubber processing operations, p. 381-387. Office of Toxic Substances, E.P.A., Wash., D.C.

Vaughn, T. W. 1918. The temperature of the Florida coral-reef tract. Papers from the Tortugas Laboratory, Carnegie Institute of Washington, D.C. 9:319-340.

Wass, R. C. 1967. Removal and repopulation of the fishes on an isolated patch coral reef in Kaneohe Bay, Oahu, Hawaii. Directed Res. Rep., Zoll. Dep., Univ. Hawaii, 77 p.

Weeks, A. 1972. Exploring the coral reefs NOAA 2(3):18-26.

Artificial Reefs off Murrells Inlet, South Carolina

R. O. PARKER, Jr., R. B. STONE, and C. C. BUCHANAN

Introduction

In recent years, many State fishery agencies have constructed artificial reefs to enhance recreational fishing. There are approximately 500 artificial reefs off the coasts of the United States (Stone, 1978) and most have been built since 1960. The most effective reefs have been built from tires, vessels, rocks, culverts, and other durable materials.

Research by Federal and State agencies and universities, showing the beneficial effects of artificial reefs on standing crops of fishes and on angular success, has stimulated reef building (Stone and Parker, 1974). Recent publications provide much of the information needed to construct reefs in fresh or salt water (Parker et al., 1974; Stone et al., 1974; Wilbur, 1974; Prince et al., 1977).

However, little information is available on how and why fishes use artificial reefs. What is available usually describes tropical or subtropical reef communities in relatively clear, warm water (Randall, 1963; McVey, 1970; Fast, 1974). Descriptions of fish behavior on artificial reefs in shallow, temperate waters are also scarce, even though these reefs are fished heavily (Buchanan, 1973; Buchanan et al., 1974). Agencies conducting studies in temperate waters are the California Department of Fish and Game (Carlisle et al., 1964; Turner et al., 1969), the New York Department of Environmental Conservation (Briggs and Zawacki, 1974; Briggs, 1975), and the National Marine Fisheries Service (Olla et al., 1974, 1975; Stone et al., 1974).

In the spring of 1971, the National Marine Fisheries Service and South Carolina Wildlife Resources Department began a study of the community structure of fishes on artificial reefs in shallow, temperate waters off Murrells Inlet, S.C., to document changes in community structure as the substrate was changed from a prereef sand bottom to a rough bottom artificial reef habitat. We monitored seasonal changes in the reef community and attempted to determine what changes were caused by recreational fishing pressure. This paper describes changes in activity in the benthic community.

R.O. Parker, Jr., is with the Beaufort Laboratory, Southeast Fisheries Center, National Marine Fisheries Service, NOAA, Beaufort, NC 28516. R. B. Stone is with Marine Recreational Fisheries, National Marine Fisheries Service, NOAA, Washington, DC 20235. C.C. Buchanan is with the U.S. Fish and Wildlife Service, 1011 East Tudor Road, Anchorage, AK 99503.

ABSTRACT—Between the spring of 1971 and the summer of 1974, the benthic community of reefs constructed of vessels and tires in 35 feet (11 m) of water off Murrells Inlet, S.C., was studied by scuba divers. Sixty-three species representing 33 families were observed; the most frequently encountered species were: black sea bass, Centropristis striata; *longspine porgy,* Stenotomus caprinus; *pinfish,* Lagodon rhomboides; spottail pinfish, Diplodus holbrooki*; pigfish,* Orthopristis chrysoptera*; tomtate,* Haemulon aurolineatum*; scad,* Decapterus *sp.; Atlantic spadefish,* Chaetodipterus faber*; cubbyu,* Equetus umbrosus*; Carolina hake,* Urophycis earlii*; sheepshead,* Archosargus probatocephalus*; and summer flounder,* Paralichthys dentatus. *Some species resided on the reefs throughout the year but fluctuated in abundance with the seasons; others were seasonal residents. Several species inhabited specific areas of the reefs. In the summer and fall, tropical fishes occupied the reefs but they rarely over-wintered. In the winter there were fewer species of fish but larger individuals.*

Study Area

Off Murrells Inlet, the natural bottom to a depth of about 35 feet (11 m) is mostly smooth sand or sandy mud with scattered patches of low profile rock outcrops. Struhsaker (1969) defined these small patches of rock outcrops, heavily encrusted with sessile invertebrates such as sponges and sea fans, as live bottom habitat and the sand and sandy mud areas as coastal habitat. He indicated that off the Carolinas the live bottoms occur at depths of 54-180 feet (17-55 m), and that inshore live bottoms near the 60-foot (18-m) contour have an invertebrate fauna less varied than those in deeper water. We found, however, that live bottom patches were scattered throughout the study area in depths less than 35 feet (11 m) and that some extended almost to the beach (Fig. 1).

Study Reefs

When we started our study, there were four artificial reefs within 13 miles (21 km) of Murrells Inlet (Fig. 1). The

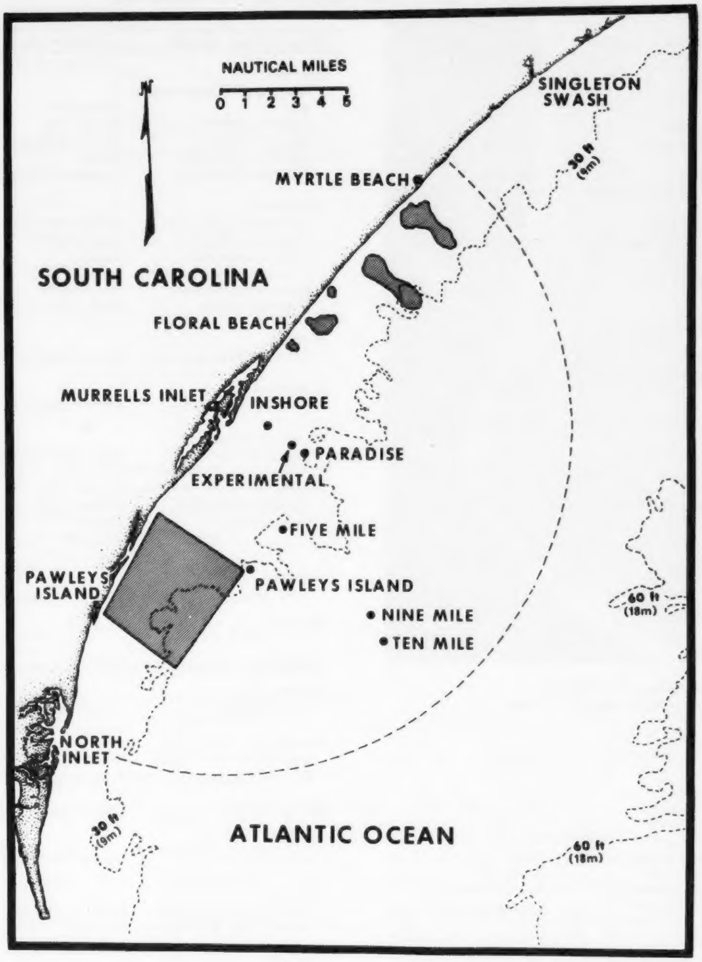


Figure 1.—Location of artificial reefs and natural rock reefs (shaded area) in our study area (dashed line) off Murrells Inlet, S.C.

State of South Carolina has since built other reefs in this area (Myatt, 1978). Paradise Fishing Reef was the largest and received more fishing pressure than the others; it was the first to have buoys maintained. This reef, built in 1968 by the Paradise Fishing Reef Association and expanded by the South Carolina Wildlife Resources Department, is located 3 miles (4.8 km) east of Murrells Inlet in 35 feet (11 m) of water. It consisted of four vessels from 26 to 140 feet (8-43 m) long and about 15,000 tires, which covered 0.01 miles^2 (0.03 km^2) of the bottom. The reef materials protruded from 1 to 15 feet (0.3-5 m) above the bottom and were covered with algae and invertebrates. We confined our studies to this reef and a smooth sandy area at a similar depth, 0.5 miles (0.8 km) inshore, where we constructed five small research reefs.

Sport Fishery

The sport fishery off Murrells Inlet extends from nearshore to nearly 60 miles (100 km) offshore. Most fishing occurs between May and November and peaks during summer. The offshore fishery (15 or more miles (24 km) offshore) comprises a dozen headboats and charter boats, and a few private boats. Headboats usually fish over rough bottom for snappers, groupers, porgies, grunts, and black sea bass. Charter and private boats primarily troll for pelagic species, but occasionally bottom fish. The nearshore fishery is composed primarily of private boats and an occasional headboat or charter boat. Bottom fishing in nearshore water yields mostly black sea bass, porgy, grunt, and summer flounder, while trolling yields chiefly Spanish mackerel and bluefish.

Paradise Artificial Reef and Pawleys Island Artificial Reef provide productive rocky habitat fisheries within easy access of most small boats (Buchanan, 1973; Buchanan et al., 1974). Private boat fishermen extensively use this improved habitat but headboats and charter boats do not. Bottom fishermen expended nearly half of their effort during the summer over the reefs and surface fishermen expended one-fifth. More bottom fish per angler-hour were caught over the reefs than over the sand bottom, but fewer than over live bottoms. The difference in catch rates between artificial and natural reefs may be due to the combined effects of high fishing intensity and more novice fishermen over the artificial reefs.

The reefs also benefited the economy of the local communities. In the summer of 1972, Paradise Artificial Reef attracted nearly 16 percent of the private boat nearshore fishermen to the Murrells Inlet area, and the money spent by these fishermen represented nearly 10 percent of the total spent by all nearshore fishermen.

Methods

In July 1971, we placed five small research reefs about 0.5 mile (0.8 km) inshore of the fishing reef to determine the effect of reefs on the distribution and abundance of fishes unaffected by fishing activities and to minimize interference with anglers on the main portion of the fishing reef. Each reef was constructed of eight-tire units,

placed 100, 150, 250, 400, and 700 feet (30, 45, 75, 121, and 213 m) from the anchor of a buoy. The reefs and anchor were connected with a 0.75-inch (2-cm) steel cable. Tire units were constructed with a base tire full of concrete anchoring three reinforcing rods that held from six to eight other tires in place. Visual, trawl, and bottom fauna surveys using scuba gear, a 15-foot (4.6-m) otter trawl over a 2,000-foot (610-m) transect, and a 0.67-foot^2 (0.06-m^2) Peterson dredge, were made prior to constructing the experimental reefs. From November 1969 through June 1974, we made 28 trips to the study area and conducted 203 underwater surveys in 76 days. Trips were scheduled once a quarter except for intensive monthly surveys in the spring, summer, and fall of 1972 and 1973.

Table 1.—Checklist of fishes observed on Murrells Inlet, S.C., artificial reefs.

Family, Genus, Species	Common name
Rajidae	
Raja eglanteria	Clearnose skate
Dasyatidae	
Dasyatis sp.	Stringray
Clupeidae	
Opisthonema oglinum	Atlantic thread herring
Synodontidae	
Synodus foetens	Inshore lizardfish
Batrachoididae	
Opsanus tau	Oyster toadfish
Antennariidae	Frogfish
Gadidae	
Urophycis floridanus	Southern hake
Urophycis earlii	Carolina hake
Syngnathidae	Seahorse
Serranidae	
Centropristis philadelphica	Rock sea bass
Centropristis striata	Black sea bass
Diplectrum formosum	Sand perch
Hypoplectrus sp.	Unidentified
Mycteroperca microlepis	Gag
Serranus subligarius	Belted sandfish
Grammistidae	
Rypticus sp.	Soapfish
Pomatomidae	
Pomatomus saltatrix	Bluefish
Rachycentridae	
Rachycentron canadum	Cobia
Echeneidae	
Remora remora	Remora
Carangidae	
Caranx crysos	Blue runner
Caranx ruber	Bar jack
Chloroscombrus chrysurus	Bumper
Decapterus sp.	Scad
Selene vomer	Lookdown
Seriola dumerili	Greater amberjack
Seriola zonata	Banded rudderfish
Lutjanidae	
Lutjanus campechanus	Red snapper
Lutjanus synagris	Lane snapper
Pomadasyidae	
Anisotremus virginicus	Porkfish
Haemulon aurolineatum	Tomtate
Haemulon sp.	Unidentified
Orthopristis chrysoptera	Pigfish
Sparidae	
Archosargus probatocephalus	Sheepshead
Calamus arctifrons	Grass porgy
Diplodus holbrooki	Spottail pinfish
Lagodon rhomboides	Pinfish
Stenotomus carprinus	Longspine porgy
Sciaenidae	
Cynoscion nebulosus	Spotted seatrout
Equetus lanceolatus	Jackknife-fish
Equetus umbrosus	Cubbyu
Leiostomus xanthurus	Spot
Menticirrhus littoralis	Gulf kingfish
Pogonias cromis	Black drum
Mullidae	
Pseudupeneus maculatus	Spotted goatfish
Ephippidae	
Chaetodipterus faber	Atlantic spadefish
Chaetondontidae	
Chaetodon ocellatus	Spotfin butterfly fish
Labridae	
Halichoeres bivittatus	Slippery dick
Tautoga onitis	Tautog
————————	Unknown
Sphyraenidae	
Sphyraena sp.	Sennet
Blenniidae	Blenny
Gobiidae	Goby
Acanthuridae	
Acanthurus sp.	Surgeonfish
Scombridae	
Scomberomorus cavalla	King mackerel
Scomberomorus maculatus	Spanish mackerel
Scorpaenidae	Scorpionfish
Triglidae	
Prionotus carolinus	Northern searobin
Bothidae	
Paralichthys dentatus	Summer flounder
Paralichthys lethostigma	Southern flounder
Balistidae	
Balistes carpiscus	Gray triggerfish
Monacanthus hispidus	Planehead filefish
Ostraciidae	
Ostracion diaphanum	Spiny boxfish
Tetraodontidae	
Spheriodes maculatus	Northern puffer

Fish Population Estimates

We estimated fish populations by direct counts when visibility was more than 4 feet (1.2 m) (it was rarely better than 8 feet (2.4 m)). We divided the reef into sections (size determined by depth of field) and counted fish at midday while stationed off to the side and above each section. Counts by two or more diver-biologists were averaged for nonseclusive fishes and all large schools of fishes (black sea bass[1], sheepshead, Atlantic spadefish, tomtate, jack and most porgy) but the highest counts were used for seclusive fishes and small schools of roving fishes (Carolina hake, cubbyu, jackknife-fish, oyster toadfish, gag, and flounder). Accuracy of fish counts varies with visibility, time of day, and species (Hobson, 1965, 1968; Stark and Davis, 1966; Turner et al., 1969; McVey, 1970). Since these factors remained relatively constant throughout our surveys, we believe that our counting error also remained constant and our estimates are an indication of true population fluctuations.

To study territorial habits and growth rates, several species were trapped and tagged with a Floy[2] dart tag inserted with a stainless steel applicator or a Floy anchor tag inserted with a tagging gun (Fig. 2). Total lengths were recorded. We offered $1-25 rewards for returned tags and catch and growth information.

Pre-Construction Surveys

The ocean bottom in the survey area was relatively barren sand with less than 10 percent natural rocky bottom (Fig. 1); it contained few encrusting

[1]Scientific names of most fishes mentioned in this paper are listed in Table 1.

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 2.—Number of organisms taken on the experimental reef site during preconstruction survey with a 15-foot (4.6 m) otter trawl over a 2,000-foot (610-m) transect.

	Trawl		
Organisms	1 12 June 1971	2 13 July 1971	3 16 July 1971
Porifera	0	1	0
Crustacea	4	5	7
Mollusca	0	0	1
Echinodermata	47	3	13
Pisces	6	4	4

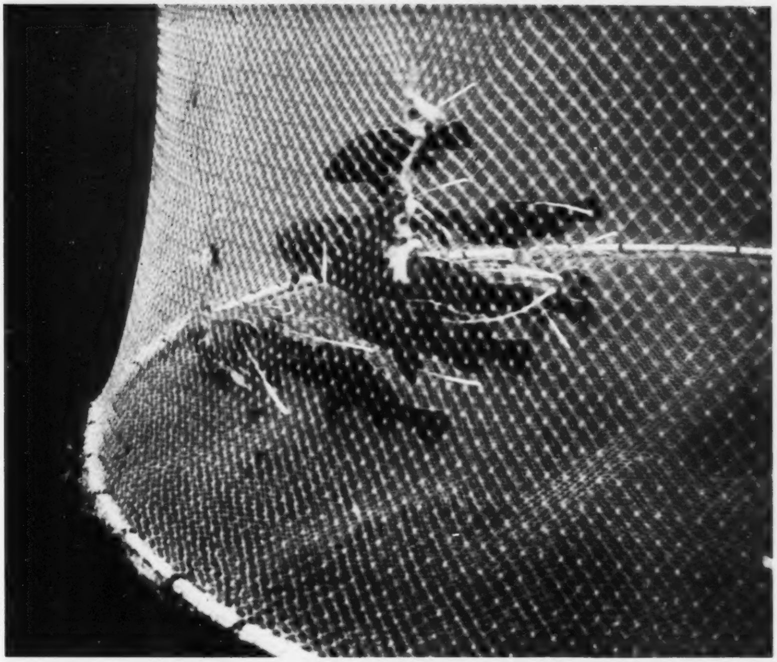


Figure 2.—Tagged black sea bass in holding net.

Table 3.—Checklist of invertebrates observed on Murrells Inlet, S.C., artificial reefs, 1971-74.

Common name	Family, Genus, Species
Sea anemone	Hydrozoa
Sponge	Porifera
Sea whip	*Plexaura flexuosa*
Star coral	*Astrangia danae*
Shortspined sea urchin	*Toxopneustes variegatus*
Longspined sea urchin	*Strongylocentrotus droebachiensis*
Sand dollar	Scutellidae
Common starfish	*Asterias forbesi*
Moss animal	Ectoprocta
Horse mussel	*Modiolus modiolus*
Horse oyster	*Ostrea equestris*
Slipper limpet	*Crepidula* sp.
Segmented worm	Polychaeta
Isopod	Isopoda
Barnacle	*Balanus* sp.
Stone crab	*Menippe mercenaria*
Blue crab	*Callinectes sapidus*
Long clawed crab	*Portunus spinimanus*
Hermit crab	*Pagurus* sp.
Spiny lobster	*Panulirus argus*
Octopus	*Octopus rugosus*
Sea squirt	*Molgula* sp.

organisms, such as oysters, hydroids, corals, sponges, and barnacles, since these animals require hard surfaces for attachment.

Two visual, three trawl, and six bottom fauna samples were obtained in June and July 1971, before construction of the experimental reef, to provide baseline data for our study. Most of the bottom was coarse sand and shell with small ripple marks from 1 to 2 inches (2.5-5 cm) high. A few sea urchins and starfish were seen. In a small patch (approximately 85 feet^2 (8 m^2), of silty bottom near the buoy anchor we saw one sea anemone, numerous tube worms, and two northern searobins. Only one game fish, a southern flounder, was caught during the trawl surveys. Fish made up only 15 percent of the catch and 70 percent of these were northern searobins (Table 2). The majority of the catch consisted of long clawed crabs[3] and shortspined sea urchins. Few invertebrates were taken in grab samples (Table 4).

[3]Scientific names of invertebrates are listed in Table 3.

Description of Artificial Reef Community

Invertebrates and Plants

Encrusting organisms began to set on the reef within a few days after it was installed (Fig. 3). Barnacles, which set in July 1971, attained an average base diameter of 0.5 inches (1.3 cm) by November and a 0.75 inch (2 cm) base diameter by March 1972. Many of the large barnacles were heavily grazed by spring (Fig. 4), probably by sheepshead and black sea bass[4], which were numerous and which frequently feed on these items (McClane, 1965).

During winter, we observed prolific invertebrate growth on the tires, with

[4]Cupka, D. 1972. Aspects of the fishery for and biology of *Centropristis striata* in South Carolina waters. Annu. rep. proj. 2-138-R-1 coop. with Natl. Mar. Fish. Serv. under P.L. 88-309:1-64 (Unpubl.).

Figure 3.—Bound tires provide good surface area for encrusting organisms and abundant cover for fishes.

Figure 4.—Encrusting organisms are heavily grazed in winter.

Table 4.—Number of organisms taken on the experimental reef site during preconstruction survey with a 0.67-foot² (0.06-m²) Peterson dredge on 13 July 1971.

	Grab Number					
Organisms	1	2	3	4	5	6
Anthozoa	0	0	several	0	0	0
Bryozoa	0	0	several	0	0	0
Annelida	5	0	1	3	4	1
Crustacea	1	2	2	0	0	2
Mollusca	1	1	0	0	0	0
Echinodermata	1	0	3	1	0	1
Cephalochordata	1	0	0	0	1	0

hydroids and sponges displaying the greatest increase in both abundance and size (Fig. 5). We found small polychaete worms and numerous small isopods and amphipods living in and on hydroids and sponges. Numerous large sea anemones were also present. Portunid crabs, the most abundant motile invertebrates observed, appeared to be occupying the same habitat used by black sea bass, pigfish, and pinfish in the warmer months.

In March 1973, we collected the following algae from the Paradise Fishing Reef: Perennials—*Codium isthmocladium*, *Sargassum filipendula*, *Champia parvula*, and *Callithamnion byssoides;* and winter algae—*Polysiphonia havanensis*, *Ceramium fastigiatum f. flaccida*, and *Bryopsis pennata*. These species are common on the rough bottom in this area.

Fishes

The observed community structure of artificial reef fishes differed considerably from that inferred from catches (Table 5). In June and July 1972, 19 species were observed, 14 were caught, but only 9 were common to both groups. Observed or caught species

composition is related to feeding habits, size of mouth, and fish behavior. Fishes seen but not caught included plankton feeders (blenny, scad, juvenile sennet, and porgy), rooters (spotted goatfish and Carolina hake), and small-mouthed fishes that are hard to hook (jackknife-fish, cubbyu, lookdown, spiny boxfish, and Atlantic spadefish). Fishes caught but not seen by divers were open bottom species (northern searobin, northern puffer, spot, and gulf kingfish) and the pelagic cobia. From 70 to 98 percent of the fish observed on the fishing reef were game fish. A total of 63 species representing 33 families were seen during the study (Table 1).

One year after the preconstruction surveys, we made quantitative estimates of fish abundance by visual counts around one of the groups of tire units on the experimental reef. We estimated 82 fish or 0.27 fish/foot^2 (0.025/m^2), a standing crop 1,814 times greater than that estimated before reef construction.

Figure 5.—Prolific winter growth of hydroids and sponges.

Fish Movement

Territoriality

To study movement of reef fishes, we tagged, on 14 occasions, 193 fish representing 12 species (Table 6). Most were black sea bass (75 percent). On 27 occasions we observed 132 tagged fish representing 7 species, and only 11 percent of these (14 black sea bass and 1 Atlantic spadefish) were seen away (100-250 feet (30-76 m)) from where they were captured and released (Fig. 6). Some of these fish moved in 1 day and most had moved within 30 days.

To determine if some of these species were residents of a particular reef, we released 18 tagged fish on a group of tires 150 feet (46 m) from where they were caught. Four of eight black sea bass, one of six longspine porgy, and the only cubbyu tagged were observed back at the capture site 2 days after they were released. Inclement weather prohibited diving the day after they were released. On five occasions over a period of 10 months one to three of these tagged fish were observed at the capture site but none were seen at the release site. Some tagged black sea bass remained on the reef throughout the year. A tagged longspine porgy was seen on the reef 33 days (17 August-19 September 1972) after it was released, and a tagged gag grouper remained on the reef from February through July when the study was terminated. Thirty-four tagged black sea bass and one tagged pigfish have been caught by fishermen in the release area. No tagged fish have been seen or caught elsewhere.

Recruitment

Two of the experimental reefs, designated "A" and "B" and located 150 feet (46 m) apart (Fig. 7), were selected in June 1973 for a recruitment study. Twenty-five fish were trapped and tagged on reef B: 19 black sea bass, 4 pigfish, 1 longspine porgy, and 1 cubbyu. One hundred twenty-one fish were removed from reef A, leaving only 10 fish (7 black sea bass, 1 pinfish, 1 Carolina hake, and 1 cubbyu). One

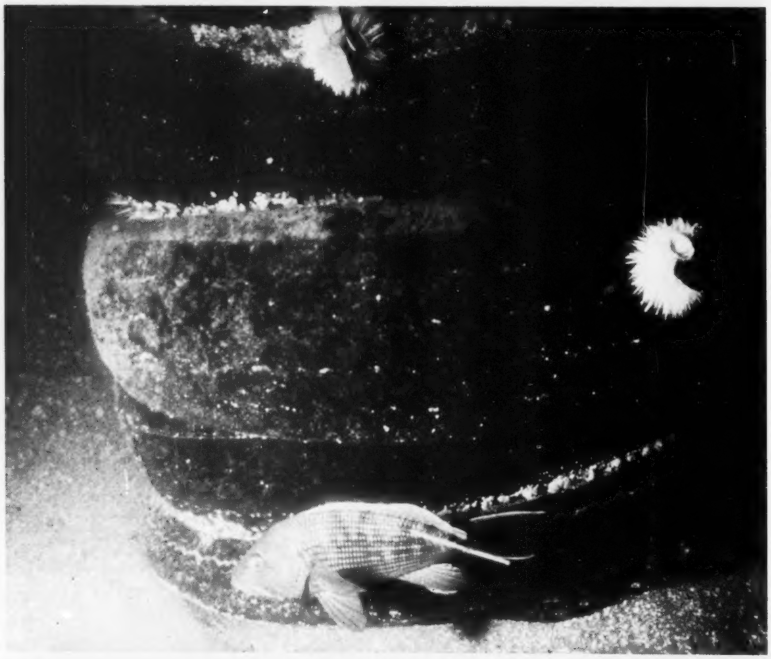
Table 5.—Paradise Artificial Reef fish community structure determined from observation and catch statistics, 1972, in percent.

	Observed			Caught		
Species	June	July	Combined	June	July	Combined
Sea bass	1.1	2.9	2.0	38.1	33.5	36.5
Black sea bass						
Rock sea bass						
Grunt		23.0	11.5	29.4	34.8	31.4
Pigfish, tomtate						
Porgy	45.7	51.8	48.8	9.0	17.2	12.0
Spottail pinfish						
Longspine porgy						
Scup, pinfish						
Flounder		0.2	0.1	7.7	7.2	7.6
Summer flounder						
Southern flounder						
Atlantic spadefish	22.8	11.5	17.2		1.8	0.7
Bluefish		8.6	4.3	0.3	0.5	0.3
Gulf kingfish				6.2	0.5	4.1
Cobia				1.8		1.1
Jack	0.7		0.3	1.0	2.7	1.6
Mackerel	0.1		0.1	0.3		0.2
Northern puffer				2.8		1.8
Oyster toadfish		0.1	0.1	0.5	1.4	0.8
Searobin				2.1		1.3
Sand perch	11.4		5.7			
Scad	11.4		4.7			
Sennet	5.7		2.9			
Lookdown		0.7	0.3			
Cubbyu	0.6	0.1	0.3			
Jackknife-fish	0.3		0.2			
Spiny boxfish	0.1		0.1			
Carolina hake		0.1				
Goatfish	0.1		0.1			
Blenny		0.8	0.4			
Spot				0.8	0.5	0.7

Table 6.—Species and numbers of fish tagged and recovered on a Murrells Inlet, S.C., artificial reef, 1972-74.

Common name	Genus, species	Tagged	Recovered
Black sea bass	*Centropristis striata*	145	34
Pigfish	*Orthopristis chrysoptera*	14	1
Oyster toadfish	*Opsanus tau*	8	
Longspine porgy	*Stenotomus caprinus*	7	
Gray triggerfish	*Balistes capriscus*	5	
Pinfish	*Lagodon rhomboides*	4	
Carolina hake	*Urophycis earlii*	4	
Cubbyu	*Equetus umbrosus*	2	
Atlantic spadefish	*Chaetodipterus faber*	1	
Summer flounder	*Paralichthys dentatus*	1	
Scup	*Stenotomus chrysops*	1	
Gag	*Mycteroperca microlepis*	1	—
Total		193	35

Figure 6.—Tagged black sea bass are easily observed underwater.



month later the number of trapable fish (those that could not escape through 7/16- × 9/16-inch mesh) increased threefold on A, to about the same number on B, which remained relatively constant (Fig. 8). This increase was due to recruitment, not growth, since there were no smaller fish observed on A the previous month. The numbers of fish dropped a little through the summer, increased in the fall, dropped in the winter, and increased again the following spring. The fall and spring influxes were also evident in black sea bass populations the previous year. No tagged fish from reef B were seen on reef A (150 feet (46 m) away), although some did move in the opposite direction up to 250 feet (76 m) along reef material spaced at intervals of 100 feet (30 m) or less. It is possible that in this area material separated by 100 feet (30 m) or less may constitute a continuous reef or territory for these species whereas material separated by 150 feet (46 m) or more may represent an isolated reef.

Seasonal Species Composition

Winter

During winter there was less species diversity and greater individual size than during summer. We noted sheepshead, black sea bass, black drum, Carolina hake, spotted seatrout, clearnose skate, sand perch, and a small gag in protected areas of the reef. Only a few black sea bass were seen on the less protected areas of the reef. Sheepshead and black drum used artificial habitat

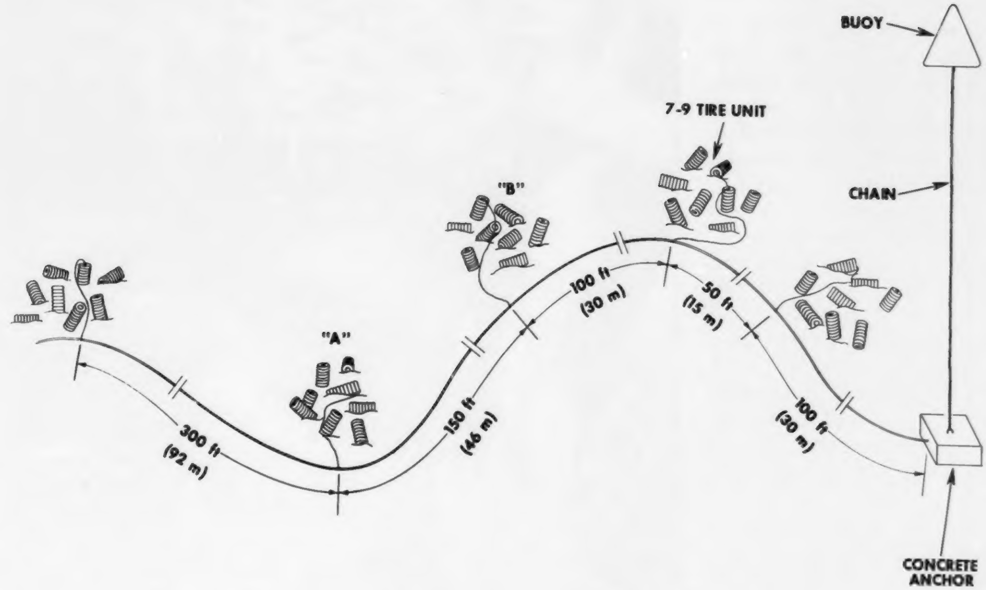
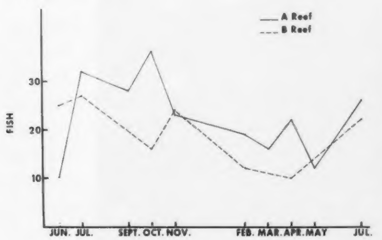


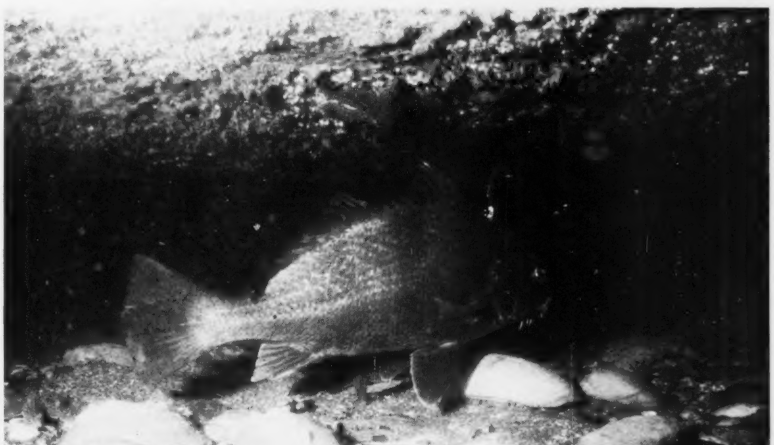
Figure 7.—Experimental reefs layout; "A" and "B" used for recruitment study.

Figure 8.—Monthly fluctuations of trapable fishes on reefs A and B, 1973-74.



mainly for shelter during cold periods (Fig. 9). On two occasions in 45°F (7°C) water, we saw dozens of 2- to 6-pound (0.9- to 2.7-kg) fish lying in a semitorpid state deep under reef material. They moved sluggishly when approached by a diver. Hundreds of active Carolina hake were seen under reef material on two occasions (Fig. 10). Six specimens with bulging abdomens, collected and examined in March, were full of crustacea, mostly crabs. Their gonads were undeveloped.

Figure 9.—Wintering black drum under cover of a barge.



Spring and Fall

Large numbers of juveniles of several species (black sea bass, longspine porgy, spottail pinfish, pigfish, and tomtate) invaded the reefs in spring and stayed through fall (Fig. 11). Young-of-the-year fishes were also prominent in spring and early summer. Hundreds of young-of-the-year and adult cubbyu and young-of-the-year black sea bass were seen under and around reef material in the spring (Fig. 12). Spotted seatrout schooled and fed around reef material in both spring and fall (Fig. 13). A few specimens, some larger than 27 inches (69 cm) total length, were caught on hook and line by South Carolina biologists.

Summer

In summer there were more species of fish and less individual size than during winter. Tropical fishes (spotfin butterflyfish, hamlet, porkfish, red snapper, slippery dick, and soapfish) used the reefs from midsummer to early fall when the bottom water

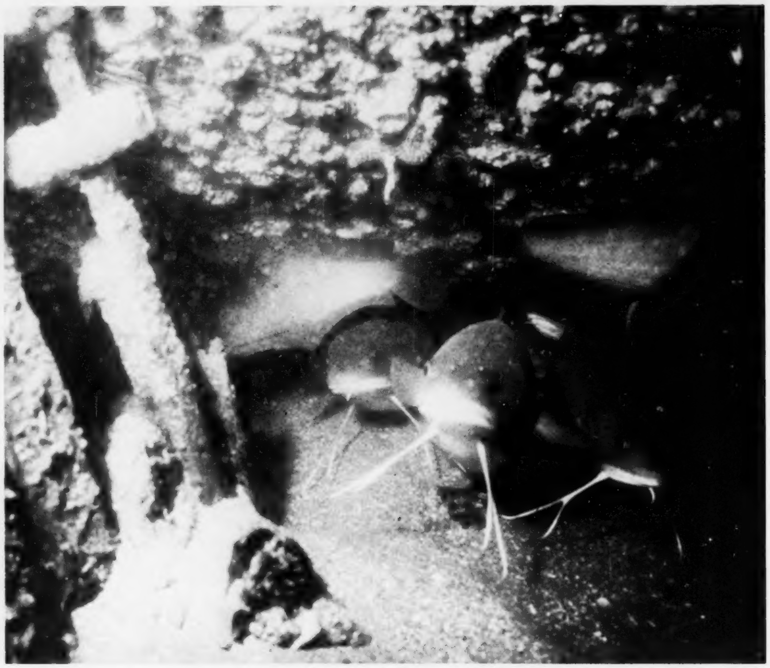
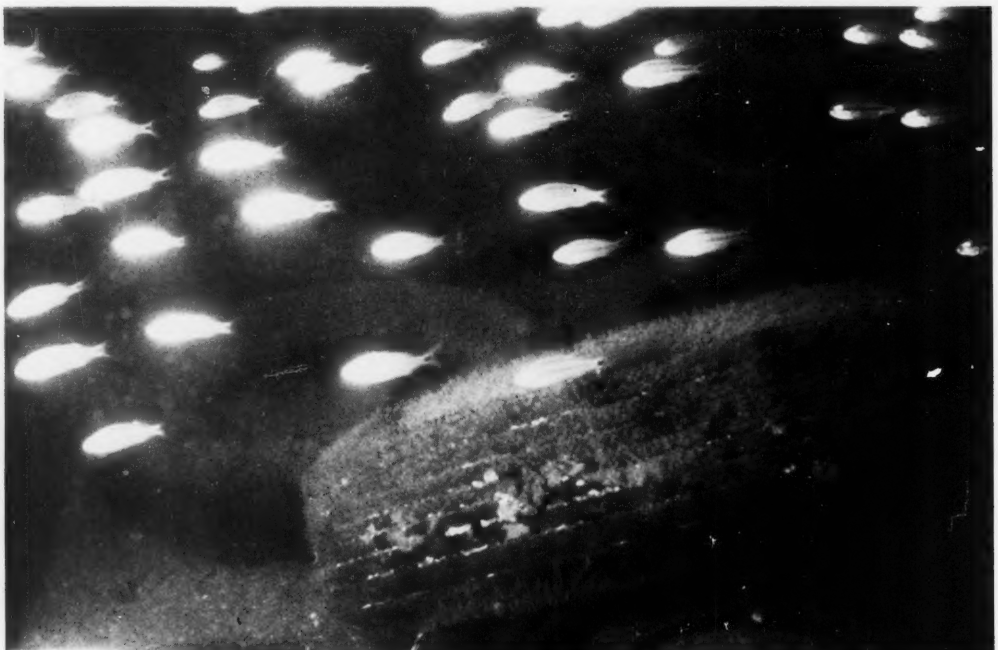


Figure 10.—Carolina hake gather under reef material during the winter for food and shelter.

Figure 11.—Juvenile tomtates are abundant in spring and early summer.



temperature exceeded 80°F (27°C) (Fig. 14). Dozens of flounder were seen during this period in, on, and beside reef material (Fig. 15). A school of 3- to 5-pound (1.4- to 2.3-kg) bluefish were observed using the inside of a landing craft during the summers of 1972, 1973, and 1974 (Fig. 16). These fish did not appear to be feeding; as divers approached, their activity increased rapidly and they quickly left the area.

Other Behavioral Observations

Growth

Three tagged black sea bass were recaptured after 174, 310, and 339 days. They had grown from 7.9 to 9.5 inches (20-24 cm), 5.5 to 8.1 inches (14-21 cm), and 7.0 to 10.1 inches (18-26 cm), respectively, an average of 0.3 inch (0.8 cm) per month. This rate was almost three times that obtained from scale analysis by Cupka (footnote 4) for 229 fish of the same size range in the South Carolina commercial fishery, and twice that obtained from scale analysis by Mercer[5] for 50 fish of the same size range collected from Murrells Inlet artificial reefs during our study.

Mutualism

On 19 September 1972, we observed spottail pinfish cleaning blue runner around a buoy anchor chain about 5 feet (1.5 m) off the bottom. Several single-tire units (ventilated tire with weight) were scattered around the anchor and spottail pinfish were feeding on organisms attached to the tires and anchor chain. As approximately 50 blue runner, 12-16 inches (30-40 cm) long, swam by the anchor chain, one to three would stop suddenly, some in a head down position. Each would then be surrounded by two to four spottail pinfish, 3-5 inches (8-13 cm) long, searching for ectoparasites (Fig. 17). Some blue runners quivered as they were cleaned. After each cleaning, which lasted several seconds, the

[5]L. Mercer, Ph.D candidate, Virginia Institute of Marine Science, Gloucester Point, Va. Pers. commun.

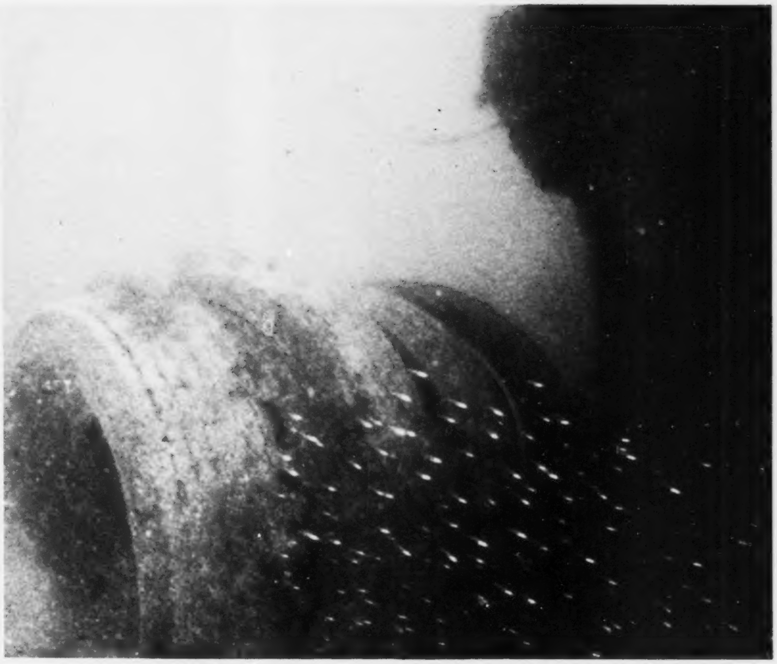
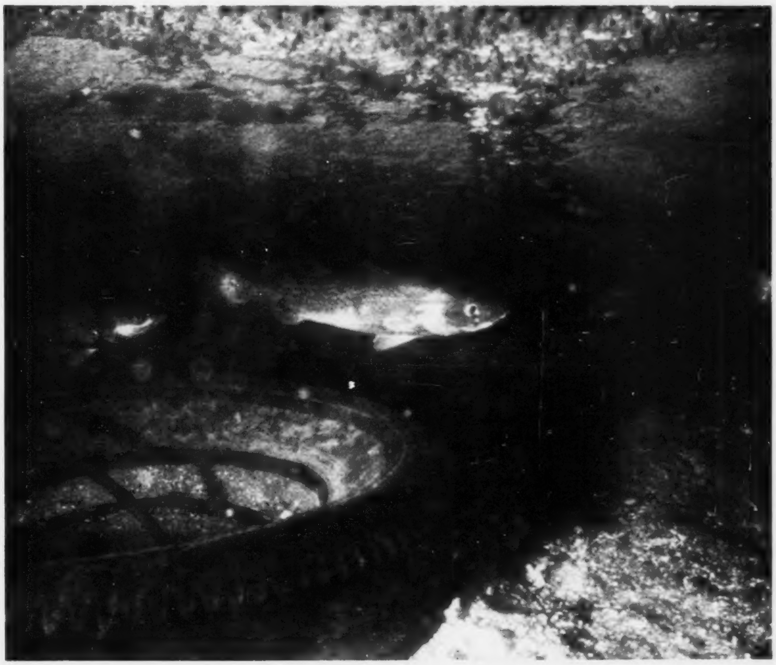


Figure 12.—Young-of-the-year fishes frequent the reefs in spring.

Figure 13.—Spotted seatrout use the reefs in spring and fall.



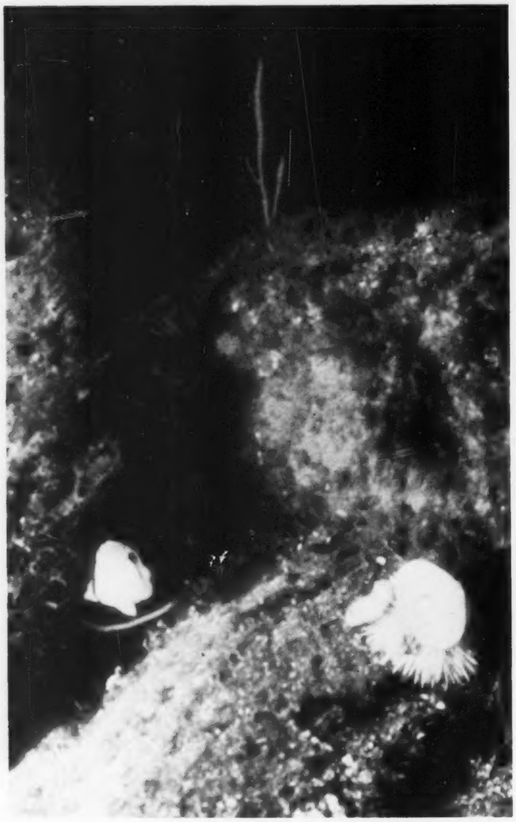


Figure 14.—Tropical fishes frequent the reefs from midsummer to early fall.

Figure 15.—Flounder are abundant in and around reef material during summer.

Figure 16.—Large schools of 3- to 5-pound (1.4- to 2.3-kg) bluefish used the inside of a landing craft during the three summers of our study.

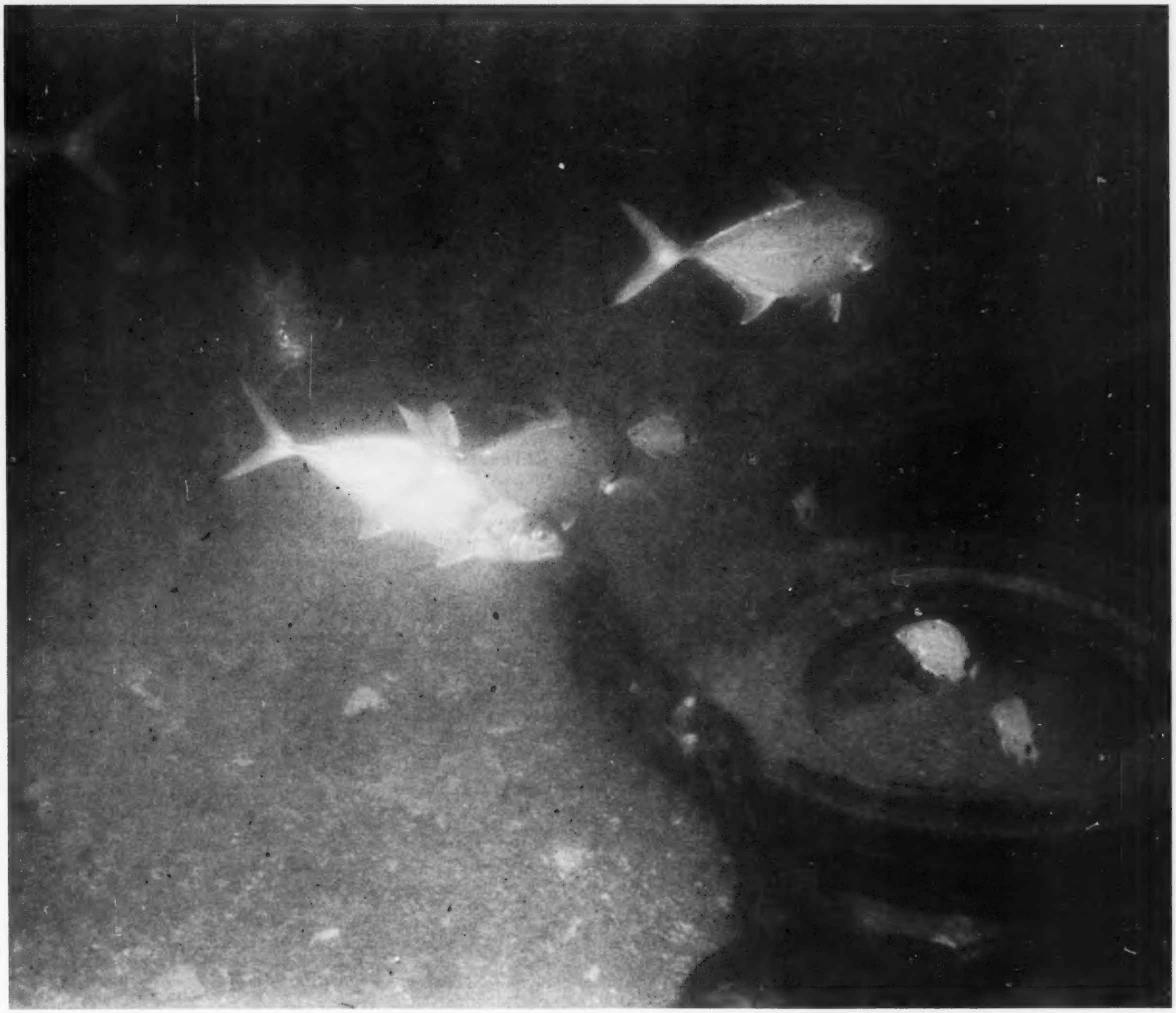


Figure 17.—Spottail pinfish cleaning blue runners.

jack continued swimming in 20-30 foot (6-9 m) circles around the buoy chain. We observed over 30 cleanings in a 45-minute period.

Porgies are known to be both cleaners and hosts. Breder (1962) observed a pinfish cleaning striped mullet, *Mugil cephalus*, and Potts (1968) observed a wrasse, *Crenilabrus melanocerus*, cleaning the porgy, *Diplodus vulgaris*. Carr and Adams (1972) found ectoparasites and scales in the stomach contents of juvenile spottail pinfish, 0.8-2.8 inches (2-7 cm) long (S.L.), collected near Crystal River, Fla. They did not find ectoparasites or scales in smaller or larger fish and hence suggested that the spottail pinfish goes through a stage in the first year of its development as a cleaner. Our observations verify that spottail pinfish are cleaners, but the fish we observed off South Carolina were larger than those collected by Carr and Adams. We determined fish sizes from visual observations and photographs of the cleaners feeding on organisms attached to anchor chain links of known dimensions.

Jacks are also known to be both cleaners and hosts; e.g., pilotfish, *Naucrates ductor*; young bar jack; and juvenile leatherjacket, *Oligoplites saurus*; are sometimes cleaners (Hass, 1953; Randall, 1962; Carr and Adams, 1972). An amberjack was observed

being cleaned by an adult porkfish[6] and bar jack have been seen being cleaned by goby, *Gobiosoma evelynae*; Spanish hogfish, *Bodianus rufus*; bluehead wrasse, *Thalassoma bifasciatum*; and juvenile gray angelfish, *Pomacanthus aureus* (Limbaugh, 1961; Collette and Talbot, 1972). However, this is the first time the blue runner has been observed being cleaned.

Summary

The artificial reefs off Murrells Inlet, S.C., provide a productive rough bottom habitat within easy access from Murrells Inlet marinas. The species composition on the reefs appears to be similar to that found on natural rough bottom habitat at the same depth in the study area.

The artificial reefs are occupied by a variety of species; some are seasonal inhabitants while others reside on the reefs throughout the year. In general, there are fewer species and larger individuals in winter than in warmer months when the influx of juveniles and tropical species increases considerably the number of species but reduces the average size.

Several observations were new to us, but are probably indicative of similar occurrences on other rough bottom areas off the Carolinas. Specifically, these were our observations of many black drum and Carolina hake using the protected areas of the reefs during the winter, apparently the same school of bluefish occupying a particular section of reef for several months and the cleaning behavior exhibited by spottail pinfish.

Based on our observations on the artificial reefs and our studies of recreational fishing by private boats out of Murrells Inlet we believe these artificial reefs are being used effectively to increase rough bottom habitat and to improve recreational fishing for species that occupy reef habitat.

Acknowledgments

We received invaluable assistance from the late Herbert Forester of Myrtle Beach, S.C., and Dewitt Myatt of the South Carolina Wildlife and Marine Resources Department. We thank Edward Flynn, University of North Carolina, for collecting and identifying plant specimens. We also express our appreciation to the owner and operators of the Gulf Stream Marine, Garden City, S.C., for the use of their facilities.

Literature Cited

Breder, C. M., Jr. 1962. Interaction between the fishes *Mugil* and *Lagodon*. Copeia 1962:662-663.

Briggs, P. T. 1975. An evaluation of artificial reefs in New York's marine waters. N.Y. Fish Game J. 22:51-56.

________, and C. S. Zawacki. 1974. American lobsters at artificial reefs in New York. N.Y. Fish Game J. 21:73-77.

Buchanan, C. C. 1973. Effects of an artificial habitat on the marine sport fishery and economy of Murrells Inlet, South Carolina. Mar. Fish. Rev. 35(9):15-22.

________, R. B. Stone, and R. O. Parker, Jr. 1974. Effects of artificial reefs on a marine sport fishery off South Carolina. Mar. Fish. Rev. 36(11):32-38.

Carlisle, J. G., Jr., C. H. Turner, and E. E. Ebert. 1964. Artificial habitat in the marine environment. Calif. Dep. Fish Game, Fish Bull. 124, 93 p.

Carr, W. E. S., and C. A. Adams. 1972. Food habits of juvenile marine fishes: evidence of the cleaning habit in the leatherjacket, *Oligoplites saurus*, and the spottail pinfish, *Diplodus holbrooki*. Fish. Bull., U.S. 70:1111-1120.

Collette, B. B., and F. H. Talbot. 1972. Activity patterns of coral reef fishes with emphasis on nocturnal-diurnal changeover. *In* B. B. Collette and S. A. Earle (editors). Results of the tektite program: ecology of coral reef fishes, p. 98-124. Bull. Los Ang. Cty. Mus. Nat. Hist. Sci. 14.

Fast, D. E. 1974. Comparative studies of fish species and their populations on artificial and natural reefs off southwestern Puerto Rico. M.S. Thesis, Univ. Puerto Rico, Río Piedras, 90 p.

Hass, H. 1953. Manta: Under the Red Sea with spear and camera. Rand McNally and Co., Chicago, 278 p.

Hobson, E. S. 1965. Diurnal-nocturnal activity of some inshore fishes in the Gulf of California. Copeia 1965:291-302.

________. 1968. Predatory behavior of some shore fishes in the Gulf of California. U.S. Fish Wildl. Serv., Res. Rep. 73, 92 p.

Limbaugh, C. 1961. Cleaning symbiosis. Sci. Am. 205(2):42-49.

McClane, A. J. 1965. McClane's standard fishing encyclopedia. Holt, Reinhart and Winston, Inc., N.Y., 1,057 p.

McVey, J. P. 1970. Fishery ecology of the Pokai artificial reef. Ph.D. Thesis, Univ. Hawaii, Honolulu, 284 p.

Myatt, D. O. 1978. Anglers guide to South Carolina artificial reefs. S.C. Wildl. Mar. Resour. Dep., Educ. Rep. 9, 30 p.

Olla, B. L., A. J. Bejda, and A. D. Martin. 1974. Daily activity movements, feeding, and seasonal occurrence in the tautog, *Tautoga onitis*. Fish. Bull., U.S. 72:27-35.

________, ________, and ________. 1975. Activity, movements, and feeding behavior of the cunner, *Tautogolabrus adspersus*, and comparison of food habits with young tautog, *Tautoga onitis*, off Long Island, New York. Fish. Bull., U.S. 73:895-900.

Parker, R. O., Jr., R. B. Stone, C. C. Buchanan, and F. W. Steimle, Jr. 1974. How to build marine artificial reefs. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Fish. Facts 10, 47 p.

Potts, G. W. 1968. The ethology of *Crenilabrus melanocercus*, with notes on cleaning symbiosis. J. Mar. Biol. Assoc. U.K. 48:279-293.

Prince, E. D., O. E. Maughan, and P. Brouha. 1977. How to build a freshwater artificial reef. Va. Polytech. Inst. State Univ., Blacksburg, Sea Grant Rep., VPI-SG-77-02, 15 p.

Randall, J. E. 1962. Fish service stations. Sea Frontiers 8:40-47.

________. 1963. An analysis of the fish populations of artificial and natural reefs in the Virgin Islands. Caribb. J. Sci. 3:31-47.

Stark, W. A., II, and W. P. Davis. 1966. Night habits of fishes of Alligator Reef, Florida. Ichthyol. Aquarium J. 38:313-356.

Stone, R. B. 1978. Artificial reefs. Water Spectrum 10(2):24-29.

________, C. C. Buchanan, and F. W. Steimle, Jr. 1974. Scrap tires as artificial reefs. Environ. Prot. Agency, Summ. Rep. SW-119, 33 p.

________, and R. O. Parker, Jr. 1974. A brief history of artificial reef research in the United States. *In* II Colloque International Sur l' Exploritation des O'ceans, Vol. 1, 10 p. Association pur l' organisation de Colloques Oceanologiques a' Bordeaux, Paris.

Struhsaker, P. 1969. Demersal fish resources: Composition, distribution, and commercial potential of the Continental Shelf stocks off southeastern United States. U.S. Fish Wildl. Serv., Fish. Ind. Res. 4:261-300.

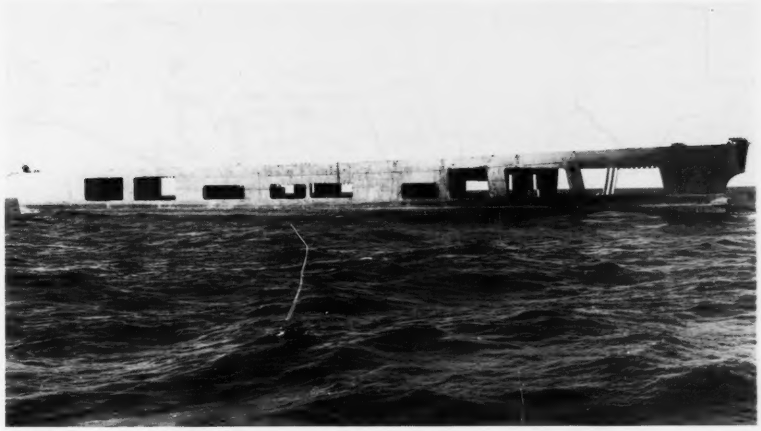
Turner, C. H., E. E. Ebert, and R. R. Given. 1969. Man-made reef ecology. Calif. Dep. Fish Game, Fish Bull. 146, 221 p.

Wilbur, R. L. 1974. Florida's fresh water fish attractors, Fla. Game Fresh Water Fish Comm., Fish. Bull. 6, 18 p.

[6]J. R. Larson. Unpublished report submitted to Broward Artificial Reef, Inc.

Access to and Usage of Offshore Liberty Ship Reefs in Texas

ROBERT B. DITTON, ALAN R. GRAEFE, ANTHONY J. FEDLER, and JOHN D. SCHWARTZ



Sinking a Liberty Ship off the Texas coast. Texas Coastal and Marine Council photo.

Introduction

Artificial reefs have been used in the United States for more than a century to establish cover and habitat for fisheries. Offshore artificial reef construction began in 1935 with the sinking of four vessels and tons of other materials off Cape May, N.J. (Stone, 1974). Initial success here led many other states to become interested in deploying offshore artificial reefs. The first reef building effort in the Gulf of Mexico was initiated in 1954 by the Alabama Department of Conservation and cooperating sportsmen's groups. They used automobile bodies to develop a series of artificial snapper banks (Stone, 1974).

The scale of offshore reef efforts changed drastically with the passage of Public Law 92-402 in 1972. Subsequently, coastal states were allowed to make application to the Secretary of Commerce for surplus Liberty Ships and to use these ships for establishing artificial reefs, the ultimate purpose being to enhance the productivity of marine fisheries.

Under the sponsorship of the Texas Coastal and Marine Council, the State of Texas requested 12 surplus Liberty Ships for reef purposes. The 12 ships were received and deployed in four areas from 8 to 36 miles offshore (Fig. 1). Three reef sites each consist of three ships sunk parallel about 300-500 feet apart at a depth of 100-110 feet (Texas Coastal and Marine Council, 1976). At the fourth reef site, the first two ships were sunk at the designated location. The third ship swamped in rough weather and lies 8 miles off Freeport at a depth of 40-50 feet. This offshore artificial reef program was completed in June 1976. Since final deployment, evaluative studies have been supported by the Texas Coastal and Marine Council to assess fisheries utilization (Vetter and Roels, 1977) and biological effects (Vetter and Roels, 1978).

Evaluative research is useful to decision makers because they need to know what programs have worked and what have not (Weiss, 1972). Besides the biological assessments made by Vetter and Roels (1977, 1978), there have been no other studies that address the success and benefits actually derived from deploying the Liberty Ships as artificial reefs. This is not surprising as most of the reef literature in general deals with the technical aspects of deployment, materials, and related fish biology (Coastal Plains Center for Marine Development Services, 1973).

However, the basic question of whether or not to deploy an artificial reef is a capital investment decision. As with most public investment decisions,

The authors are with the Department of Recreation and Parks, Texas A&M University, College Station, TX 77843. This research was funded by the Texas Coastal and Marine Council, the Texas Agricultural Experiment Station, and the Texas A&M Sea Grant Program.

ABSTRACT—Although artificial reefs have been deployed to increase fish stocks in the United States for over a century, few studies have been done to evaluate the benefits of such reefs. This study seeks to identify the extent to which the Texas Liberty Ship reefs are used by recreational fishermen.

Two independent surveys were used to address the two principal means of gaining access to Liberty Ship reefs. One study focused on the Texas charter and party boat fleet and the other on private boat fishermen residing in the Houston-Galveston metropolitan area.

The Liberty Ship reefs were found to attract a substantial number of private boat and charter/party boat fishermen, especially when the extent of use is compared with other site-specific artificial or natural offshore attractions. Nearly all use of the Liberty Ship reefs originated from the closest access point. Use of a particular reef site appears to be related to the availability of alternative fishing grounds and the capability to travel great distances offshore.

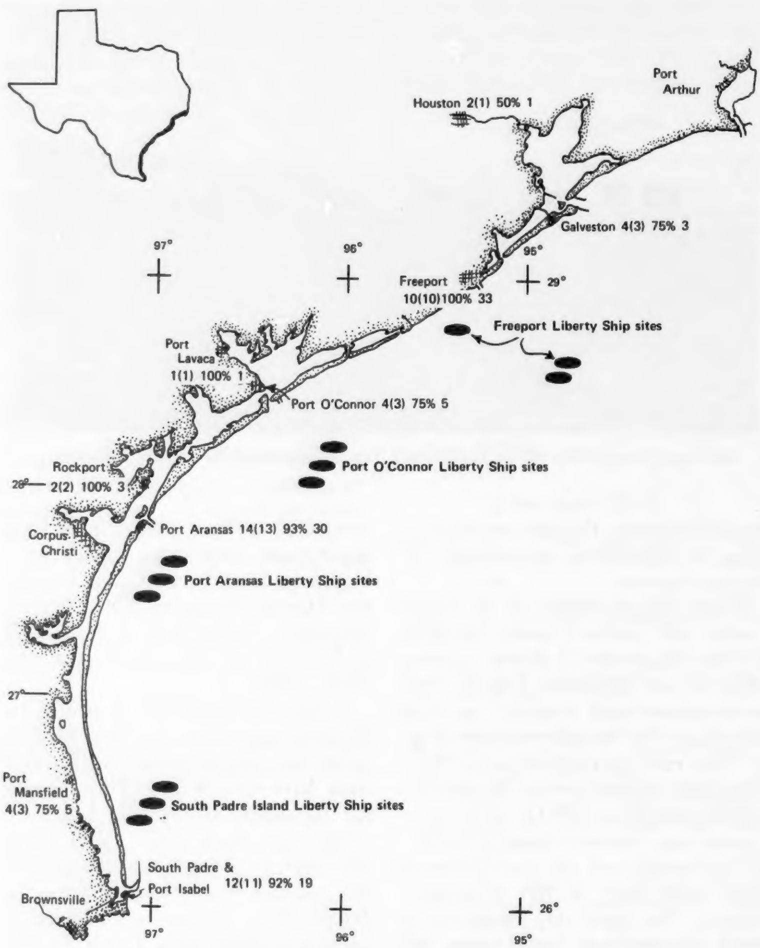


Figure 1.—Location of Texas Liberty Ship reefs and location of Texas charter/party businesses operating in 1977: population, (sample size), response rate, and number of vessels.

Daniel and Seward (1974) suggested benefit-cost analysis. Determining the costs of reefs is far less complex from a theoretical and empirical viewpoint than determining benefits. Daniel and Seward (1974) identified three benefits which can result from the creation of artificial reefs: 1) Increased productivity of the waters surrounding the reef in terms of amount of aquatic and marine life which can be supported, 2) greater fishing success for those fishermen who fish in the waters surrounding the reef, and 3) because of 1 and 2, the attraction of fishermen to the area. These are what can occur. Only a few evaluative studies have established the extent to which artificial reefs are used for fishing, by whom, the fishing success, and the economic impact (Buchanan, 1972, 1973; Liao[1]).

Although most studies have generally shown that man-made habitats improved catch rates and had a beneficial impact on the local economy, few systematically address the topics of access and spatial relationships.

[1]Liao, D. S. 1978. Economic impact of offshore sport fishing over artificial reefs and natural habitats in South Carolina. Unpubl. manuscr., 54 p. Mar. Resour. Res. Inst., Charleston, S.C.

Parker et al. (1974) mention accessibility as a critical ingredient to a successful reef. Improved catch and economic impact depend on people being able to reach and use the reefs. If reefs are not generally accessible, these benefits are less likely to occur. As we move toward specific siting criteria that fisheries managers can use in deploying offshore reefs, we need to know considerably more about the extent to which reefs at various offshore locations are used.

This study aims to provide data toward further understanding of reef use and spatial relationships. In addition, findings serve as a baseline against which future evaluations of reef use can be viewed.

Objective

The objective of this study is to identify the extent to which the Texas Liberty Ship reefs are used for recreational fishing. This information is needed to better understand the nature of the public investment in Liberty Ship reefs in Texas.

Methods

To achieve this objective, two independent surveys of fishermen were conducted. One focused on charter and party boat operators along the entire Texas coast and their use of the Liberty Ship reef sites. The other survey focused on private boat fishermen residing in an eight county study area, encompassing the Houston/Galveston metropolitan area, and their use of the Freeport Liberty Ship reef sites. The private boat survey has a regional focus to allow a detailed description of fishing patterns relative to Liberty Ships. The Houston/Galveston region of the Texas coast provides a particularly interesting case study because usage patterns for two Liberty Ship reef sites can be compared and implications of their respective locations can be drawn. The two surveys address the only two means of accessing the Liberty Ship reefs for fishing purposes.

A 1975 Texas Parks and Wildlife Department survey of finfish harvest in Galveston Bay indicated that over 90 percent of all Bay anglers came from

Harris, Galveston, Chambers, and Brazoria counties, all of which border on Galveston Bay (Heffernan et al., 1975). A second group of counties, including Fort Bend, Liberty, Montgomery, and Waller, was added to the previous four counties adjacent to Galveston Bay to form the study area for the survey of boat fishermen (Fig. 2). Therefore, it is probable that nearly all private boat fishing use of Galveston Bay and adjacent offshore waters is done by residents of the study area. It is important to recognize that the focus of the private boat survey is on fishing participation by people residing within the eight county area, not on total fishing use of Galveston Bay and adjacent offshore waters. Some additional fishing use is contributed by private boat fishermen entering from outside the study area, but as indicated above, this is probably a small portion of total use.

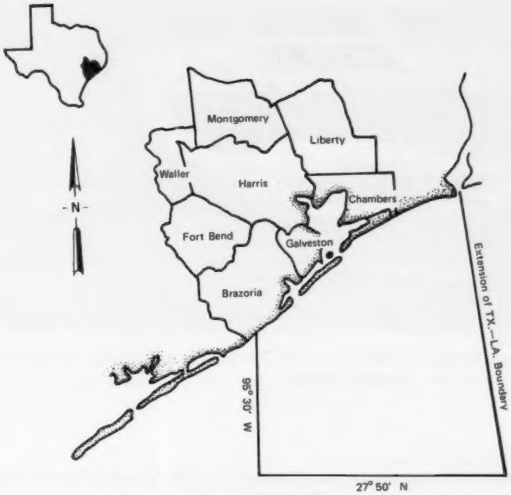


Figure 2.—Map of the eight county private boat study area.

Charter/Party Boat Operator Survey

Since we were interested in Liberty Ship reef use only, all charter/party boat operators who fished exclusively in the bays were systematically excluded. Charter and party boats were aggregated since there was often no clear distinction between them. Many operations used boats for both charter and party trips. Also, some operations ran regularly scheduled trips on a per person basis during the peak season and operated on a charter basis for the rest of the year. Some operations acted as agents for other captains. These were considered multiple boat operations and usage figures were calculated accordingly for each operation.

A total of 58 Gulf operators were identified along the Texas coast. Five operators were excluded from the population due to discontinued service or an unknown address. Each of the remaining 53 Gulf operators was sent a mail questionnaire. This was followed by a second mailing and telephone interviews with nonrespondents. Forty-seven usable responses were received for a response rate of 89 percent. Figure 3 presents the total number of Gulf operators working for each coastal port and the respective percentage of response.

Houston/Galveston Boat Fishermen Survey

We recognized that not all boat owners fish and of those that do, not all fish Liberty Ship reefs. Some boaters fish in freshwater only while others fish freshwater and saltwater. Some saltwater fishermen fish in bays only or offshore only with others fishing in both locations. Therefore, it was necessary to select a sample of sufficient size to be statistically meaningful with regard to subsample findings, for example those who fished Liberty Ship reefs.

There were 113,397 registered pleasure boats in the eight county study area as of October 1977, according to the Texas Parks and Wildlife Department's computerized boat registration file. Boats were classified into categories of less than 26 feet in length and 26 feet in length or longer. A sample of 1,500 (1.34 percent) was drawn from all boats less than 26 feet in length. The number of boats needed from each of the eight counties to provide the sample size was calculated based on a constant sampling proportion. The Texas Parks and Wildlife Department computer then selected from the registration file the specified number of entries from each county using systematic sampling with a random start. The entire population of 1,953 boats 26 feet or longer was included since it was expected that these boats would have a greater propensity to travel offshore to fish and thus utilize the Liberty Ship reefs.

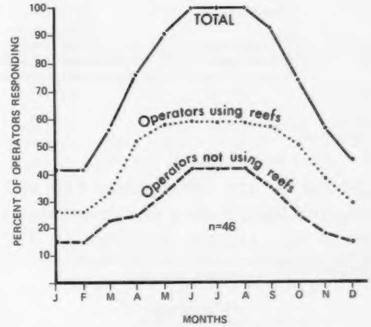


Figure 3.—Seasonality of charter/party operators.

A pretested survey questionnaire was sent to the sample of 3,453 boat owners in March 1978. The total usable response rate for the survey was 50.3 percent. Telephone interviews were conducted with a sample of approximately 200 nonrespondents to

Liberty Ship settles stern first into Gulf waters off Texas. Texas Coastal and Marine Council photo.

Table 1.—Description of charter/party boat operations that used and did not use the Liberty Ship reefs.

Item	Number of operations	Number of vessels in operation	Average number of vessels per operation	Number of trips made to Gulf	Average number of trips per operation	Average distance traveled into Gulf
Reef users	27	72	2.7	4,895	[1]188.3	30.7
Non-reef users	20	28	1.4	1,351	[2]79.5	24.7
Total	47	100		6,246		

[1]Average based on 26 operations which indicated the number of trips they made.
[2]Average based on 17 operations which indicated the number of trips they made.

control for any nonresponse bias and improve the accuracy of extrapolations from the sample findings to the population.

Findings

Charter/Party Boat Operator Survey

Of the 47 operations that responded, 27 (57 percent) indicated they used the Liberty Ship reefs since they were deployed in 1976 (Table 1). These 27 reef-using operations accounted for 72 vessels whereas non-reef-using operations had only 28 vessels. Therefore, the average number of boats was 2.7 and 1.4 for reef-using and non-reef-using operations, respectively. The reef-using operations reported a yearly average of 188 trips into the Gulf, or 72.3 trips per vessel. The non-reef-using operations reported an average of 80 trips into the Gulf, or 57.1 trips per vessel. These findings indicate that in terms of number of vessels and trips, the reefs are used mainly by the larger, multiple boat operations. However, of the 4,895 trips made into the Gulf by the reef-using operations, 600 trips, or 12 percent, were made to the Liberty Ship reefs.

Reef users traveled further seaward than non-reef users. Average one-way distances traveled were 30.7 miles and 24.7 miles for reef users and non-reef users, respectively. For all port areas except Houston and Galveston, however, the average one-way distance traveled seaward by both reef users and nonusers was in excess of the distance to the adjacent reef location. This would indicate that most of the charter/party boats are going beyond the Liberty Ships to other fishing locations.

In addition to the extent of Liberty Ship usage, seasonality of fishing use was investigated. The seasonality of Gulf fishing by reef-users is compared with that of non-reef-users in Figure 3. As shown, 74 percent or more of the operators are engaged in Gulf fishing between April and October. Forty-eight percent of the reef-using operations reported that the Liberty Ship reefs increase the length of their fishing seasons. Many of these operators reported using the reefs in the spring or fall when other forms of fishing were not available. Liberty Ship reef users tended to have periods of inoperation due to a lack of customers whereas nonusers claimed more often that the inoperation was due to a lack of sport fish. This makes sense since the Liberty Ship reefs would increase the number of sport fish but not the number of customers. Therefore the season for reef users is determined to a greater extent by customer demand than the availability of sport fish. The lack of sport fish will affect smaller non-reef-using operations that specialize in fishing for one kind of species, particularly when that species has a specific natural season.

A regional difference is shown in Figure 4 where findings from the South Padre/Port Isabel area are compared with the rest of the coast. Reef-using operations outnumber non-reef-using operations on the rest of the Texas coast while the opposite is true in the South Padre/Port Isabel area. Only 43 of the approximately 600 trips to the Liberty Ship reefs were generated from the latter port areas and 30 of these ships were from a single operator. Most South Padre/Port Isabel operators indicated that the Liberty Ship reefs are too far from shore and that an array of fish are available within a shorter distance from the harbor. Also, South Padre/Port Isabel's southernmost location allows for a longer season and the outer continental shelf is closer to shore giving greater water depths at shorter distances.

Thus, for several reasons South Padre/Port Isabel operators use alternative fishing grounds. Other Texas operators have to travel farther to find alternative fishing areas and tend to make greater use of the new reef resources. Of the approximately 600 trips taken to the Liberty Ships, 557 were to the three northernmost reef areas.

Charter/party boat use of the Freeport Liberty Ship sites originated almost exclusively from Freeport.

Only 2 percent of the trips from Galveston were to the Liberty Ship reefs. The reason reported most often as to why there was so little use from Galveston was that the reefs are too far from the harbor (52 miles).

Eight out of the 10 operators from Freeport used the Liberty Ship reefs. All 10 operators made a total of 2,159 trips into the Gulf. Of these trips, 8 operators made 246 of them to the Liberty Ship reefs. This accounts for 11 percent of the total charter and party boat fishing activity from Freeport.

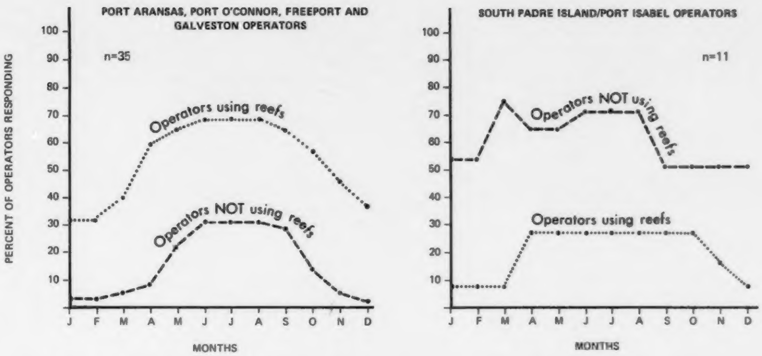


Figure 4.—Seasonality of charter/party use and non-use of the Liberty Ship reefs.

Houston/Galveston Boat Fishermen Survey

The offshore area adjacent to the Galveston Bay system includes a wide variety of artificial fishing attractions in addition to the natural reefs and banks that occur in the area (Fig. 5). Survey results indicated that 5,542 boats were used for fishing this offshore area during 1977. These boats accounted for 66,924 offshore fishing trips during the study year.

Table 2 provides the distribution of this offshore fishing activity across alternative fishing attractions. It is readily apparent from the table that the two Liberty Ship sites in this area accounted for only a small portion (5 percent) of the total number of offshore fishing trips. Fishing around oil platforms was the dominant type of offshore fishing, accounting for 50 percent of all offshore trips. Trolling, which cannot be attributed to any particular type of attraction, accounted for another 31 percent of offshore trips. Three other specific artificial attractions, the Fish Haven, V. A. Fogg, and S. E. Lump, collectively accounted for about as much fishing (6 percent) as the Liberty Ship reefs. Finally, natural reefs and banks attracted about 8.3 percent of the fishing trips during the study year.

When interpreting these findings it is important to remember that, although the Liberty Ships accounted for a small portion of offshore fishing, they represent only two specific offshore fishing sites intermixed among many alternative attractions (Fig. 5). The dominance of oil platform fishing in this area is probably a function of the large number (approximately 138) of oil platforms found at varying distances from shore and major population centers. When fishing participation at Liberty Ships is compared with that at other site-specific attractions or at natural reefs as a whole, the Liberty Ships appear to constitute a significant and competitive attraction to offshore fishermen.

Further insight into the use of Liberty Ships can be gained by considering two additional variables: boat size and port of origin. Relative to boat size, Table 3 presents the distribution of Liberty Ship fishing participation for boats less than 26 feet in length versus those 26 feet or longer. As would be expected, given the relative abundance of smaller boats in the study area, most of the trips to the Liberty Ships were made by boats less than 26 feet in length.

The usual notions of decay in "consumption," or participation, with increasing distance from population centers would suggest that the nearshore ship should be used more than the offshore ship (Clawson and Knetsch, 1966). This is because the costs (in both time and money) of participation are lower for the nearshore reef and hence consumption should be greater at the nearshore location. In general this pattern was observed, but there was a marked contrast in use by boat size between the nearshore ship and the offshore ship.

Table 2.—Extent of fishing participation during 1977 at various offshore fishing attractions.

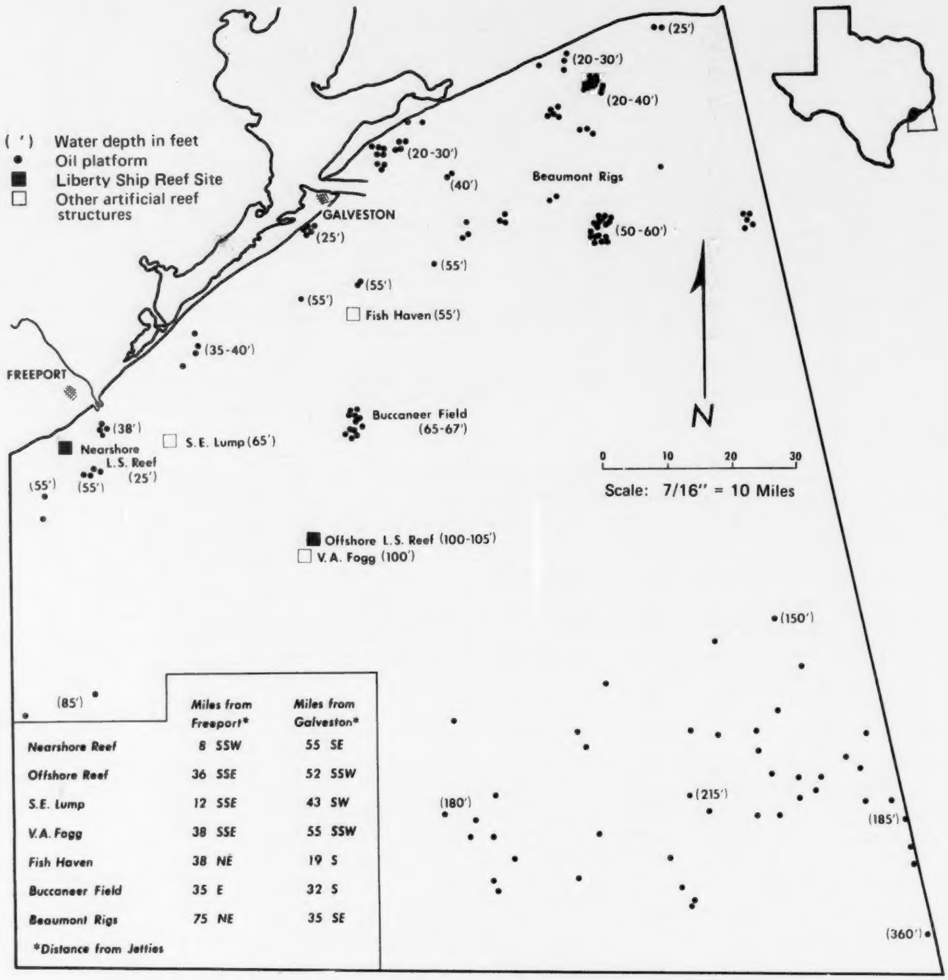
Attraction	No. of trips in 1977 (n=358)	Percent of total trips	No. of person-trips
Nearshore Liberty Ship	1,895	2.8	8,149
Offshore Liberty Ship	1,493	2.2	6,719
Oil platforms	33,434	50.0	133,870
Other artificial attractions[1]	3,959	6.0	15,564
Natural reefs	5,588	8.3	20,676
Trolling (not place specific)	20,555	30.7	84,276
Total	66,924	100.0	269,254

[1]Includes Fish Haven, V.A. Fogg, and S.E. Lump.

Table 3.—Extent of Liberty Ship fishing during 1977 by boat length category.

Attraction	No. of trips-boats less than 26 feet (n=51)	No. of trips-boats 26 feet or longer (n=307)	Total
Nearshore Liberty Ship	1,663	232	1,895
Offshore Liberty Ship	1,078	415	1,493
Total	2,741	647	

The nearshore ship received considerably more fishing use by boats under 26 feet as would be expected, but the offshore ship was used to a greater extent by the larger boats. In fact, the larger boats accounted for almost one-third (28 percent) of the fishing trips to the offshore reef while they accounted for only 12 percent of the fishing trips to the nearshore reef. Thus, boats 26 feet or longer showed a reversal of the expected distance decay



	Miles from Freeport*	Miles from Galveston*
Nearshore Reef	8 SSW	55 SE
Offshore Reef	36 SSE	52 SSW
S.E. Lump	12 SSE	43 SW
V.A. Fogg	38 SSE	55 SSW
Fish Haven	38 NE	19 S
Buccaneer Field	35 E	32 S
Beaumont Rigs	75 NE	35 SE

*Distance from Jetties

Figure 5.—Map of the offshore area adjacent to the Galveston Bay system.

relationship: almost twice as many trips by such boats were made to the more distant reef. This finding suggests that variables other than distance are considered by offshore fishermen in selecting fishing locations. Considerations of water depth as it relates to species of fish sought, for example, probably draw many fishermen beyond the nearshore Liberty Ship. Thus, the nearshore ship may be a popular attraction for those boats which are limited by their size and equipment to staying within a few miles of shore, but the offshore ship site and its related fisheries are more attractive to those which have the capability of traveling 30 miles or farther offshore.

Considering the port of origin of Liberty Ship fishermen provides further insight into patterns of participation. Most fishermen in the region generally launch their boats at Freeport or Galveston, although some boats are kept in marinas or launched at other locations along the coastline. However, nearly all of the fishing at the Liberty Ships originates from Freeport, the closest access point. Table 4 presents the percentage of offshore fishermen utilizing each major access point who used the Liberty Ships during the study year. Despite the relatively large number of fishermen who launch at Galveston, almost none of them traveled the 50 or more miles to reach either Liberty Ship site. On the other hand, a noticeable proportion of Freeport fishermen did utilize each reef. When one considers the 5 percent of offshore trips that Liberty Ships account for in terms of the relatively large size of the regional population and the fact that nearly all of these trips are channeled through Freeport, it is apparent that the impacts of the Liberty Ships on this single local community could be considerable.

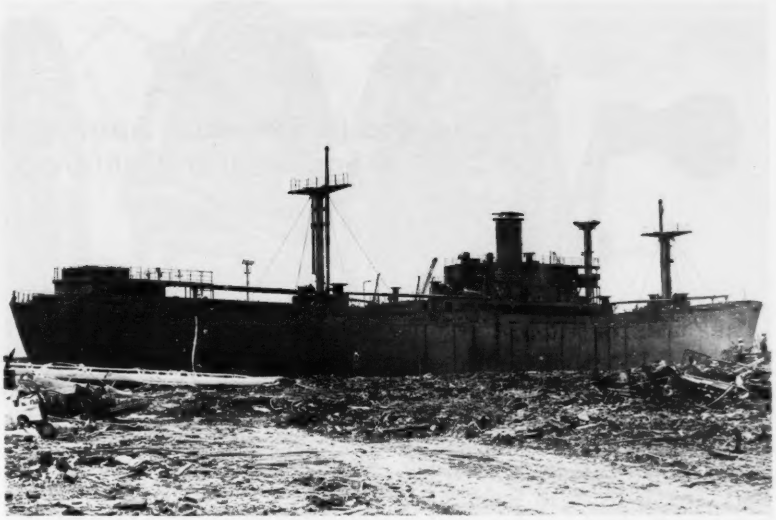
Table 4.—Relative distribution of participation in Liberty Ship fishing by major access point.

	Boats less than 26 feet		Boats 26 feet or longer	
Attraction	Percent of Freeport offshore fishermen (n=19)	Percent of Galveston offshore fishermen (n=23)	Percent of Freeport offshore fishermen (n=104)	Percent of Galveston offshore fishermen (n=108)
Nearshore Liberty Ship	26	0	21	1
Offshore Liberty Ship	11	4	30	3

Conclusions

To what extent are the Texas Liberty Ships used for recreational fishing? This study indicates that the ships attract both private boat and charter/party boat fishermen. The ships probably have the greatest impact on the charter/party boat fishery for they contribute to the livelihood of the operators and create recreational opportunities for the customers. While they account for 10 percent of all offshore trips by charter/party boats, the Liberty Ships extend the season for some operators by providing concentrations of fishes at locations and at times when they would otherwise be lacking. Relative to private boat fishing, the Liberty Ships account for a portion of offshore fishing which is comparable with the extent of fishing at other site-specific artificial or natural offshore attractions.

Nearly all use of the northernmost reefs (charter/party and private) was found to originate from the closest access point, Freeport. The attraction of the reefs did not appear to extend to nearby access points or population centers, as illustrated by the relative lack of Galveston fishermen who used the reefs. Further, the effect of location of the reef, or distance, appears to be related to both the availability of alternative fishing grounds and the capability to travel great distances offshore. Regional differences in charter/party boat use patterns suggested that competing opportunities was an import factor influencing whether or not the ships were used. Private boats similarly showed a sensitivity to the supply of alternative attractions but also were limited in the distances they could travel offshore by their size and equipment. The nearshore reef (8 miles from Freeport but only 4 miles from land) was more popular among small boats which are generally incapable of traveling farther offshore. The offshore reef (36 miles from Freeport), on the other hand, was more popular among larger boats with greater travel capability, suggesting that perhaps the offshore ship provides a better "quality" reef for the relatively few whose boats are able to reach it.



A Liberty Ship is prepared for use as an artificial reef. Texas Coastal and Marine Council photo.

This study has focused on recreational fishing use of Liberty Ships as one category of benefits that have resulted from this public investment program. This is not to imply that there are no other benefits of the program nor that there are no costs. To fully comprehend the merits of the decision to deploy ships as reefs in Texas and elsewhere, further research should focus on analyses of all costs and benefits associated with each program.

Literature

Buchanan, C. C. 1972. A comparison of sport fishing statistics from man-made and natural habitats in the New York Bight. Coastal Plains Cent. Mar. Dev. Serv., Semin. Ser. 1:27-37.

________. 1973. Effects of an artificial habitat on the marine sport fishery and economy of Murrells Inlet, South Carolina. Mar. Fish. Rev. 35(9):15-22

Clawson, M., and J. L. Knetsch. 1966. Economics of outdoor recreation. The Johns Hopkins Press, Baltimore, 328 p.

Daniel, D. L., and J. E. Seward. 1974. Natural and artificial reefs in Mississippi coastal waters: Sport fishing pressure and economic considerations. Bur. Bus. Res., Univ. South. Miss., Hattiesburg, 27 p.

Heffernan, T. L., A. W. Green, L. W. McEachron, M. G. Weixelman, P. C. Hammerschmidt, and R. A. Harrington. 1975. Survey of finfish harvest in selected Texas bays. Tex. Parks Wildl. Dep. Proj. No. 2-231-R-1, Austin, Tex., 115 p.

Parker, R. O., Jr., R. B. Stone, C. C. Buchanan, and F. W. Steimle, Jr. 1974. How to build marine artificial reefs. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Fish. Facts 10, 47 p.

Steimle, F., and R. B. Stone. 1973. Bibliography on artificial reefs. Coastal Plains Cent. Mar. Dev. Serv. Publ. 73-2, 129 p.

Stone, R. B. 1974. A brief history of artificial reef activities in the United States. *In* Proceedings: Artificial reef conference, p. 24-27. Tex. A&M Univ. Cent. Mar. Res., Houston.

Texas Coastal and Marine Council. 1976. Liberty Ship reef program. Public Brochure.

Vetter, R. D., and O. A. Roels. 1977. An assessment of the sportfishery on artificial Liberty Ship reefs off Port Aransas, Texas. Rep. to Tex. Coast. Mar. Counc., Univ. Tex. Mar. Sci. Inst., Port Aransas Mar. Lab., 11 p.

________, and ________. 1978. The icthyofaunal composition and trophic interactions of the artificial Liberty Ship reefs off Port Aransas, Texas. Rep. to Tex. Coast. Mar. Counc., Univ. Tex. Mar. Sci. Inst., Port Aransas Mar. Lab., 13 p.

Weiss, C. H. 1972. Evaluation research; methods for assessing program effectiveness. Prentice-Hall, Englewood Cliffs, N.J., 160 p.

Changes in Saltwater Angling Methods and Gear in California

SUSAN E. SMITH

Introduction

In California, as in most other coastal states, saltwater recreational fishing has increased rapidly over the years, and is likely to continue to increase. Recreational fish stocks, however, only have the capacity to yield a limited sustained catch.

To manage a recreational fish stock rationally, its relative abundance must be monitored over a period of time. One method widely used in assessing relative abundance is the collection and analysis of catch per unit of effort data (i.e., catch per angler hour, catch per angler day). Researchers recognize, however, that there are other factors to consider when assessing abundance by this technique. One such factor is the change in efficiency of fishing gear and methods over a period of time. Actual reduction of fish stocks, if measured by catch-per-effort alone, may be masked by increased efficiency in gear and/or methods, so that there would appear to be little, if any, decline in the stock (Gulland, 1968).

One of the first steps in approaching and understanding this problem is to document important changes in angling techniques and tackle, and the approximate times these changes have taken place. Descriptions of commercial fishing gear and methods have been documented by Scofield (1929, 1947, 1948, 1951a, 1951b, 1956), Fry (1931), Whitehead (1931), Croker (1938a), and others. Information on commercial gear and techniques has also been gathered by the State of California since 1916. This type of information is not available for California's marine recreational fisheries, except in scattered reports in the scientific literature and in popular articles.

This report traces developments in saltwater angling equipment from just before the turn of the century to the present. It also presents some examples of California fisheries that have been affected by developments in sportfishing methods and equipment, and documents current methods and tackle used in these fisheries.

Susan E. Smith is with the Tiburon Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, 3150 Paradise Drive, Tiburon, CA 94920.

General Developments

California saltwater recreational fishing had its beginnings during the last decades of the 19th century. In the early days of the sport, it appears that most offshore fishing was conducted with handlines, except for a select group of big game anglers who fished for bluefin tuna off Catalina Island and a few salmon trollers in Monterey Bay (Collins, 1892; Holder, 1914; French, 1916). No doubt some people used fly-fishing and freshwater baitcasting tackle for some of the smaller inshore and anadromous species around river mouths and in creeks and bays, but there is little specific information of the type of tackle used in these areas.

Hexagonal split bamboo rods had been introduced in the United States around 1870 (Marden, 1965), and rods made of plain bamboo (Calcutta type) were also available before the turn of the century, as were a variety of hardwood rods made of Cuban lancewood, hickory, South American greenheart, and bethabera. Multiplying baitcasting reels[1] were in use, but only a few were designed for saltwater fishing. Because these early multipliers did not have an internal drag or free-spool mechanism, the reel handles would spin wildly when casting or when a fish ran with the line. For this reason they were coined "knucklebusters." Pressure was applied to the outgoing line by a leather thumb brake.

Fishing line was usually tarred cotton or twisted linen. The last, called "cuttyhunk," became the most popular for saltwater use and consisted of strands of Irish linen. Each strand or ply of the most common type (25-lea[2]) had a breaking strength of about 3 pounds per strand dry, and 5 pounds wet; a more specialized line (50-lea) tested at 2 pounds per strand when dry and 3 pounds when wet (A. W. Agnew, Sunset Line and Twine, Petaluma, Calif., pers. commun.). Cuttyhunk became the standard in ocean angling until supplanted by nylon and Dacron[3] after the second World War. Linen line was combined with a variety of leader materials, usually gut or wire.

[1]Multiplying reels, as opposed to single-action types, are geared to give increased retrieving speed, the spool revolving several times with each turn of the handle.

[2]A unit of measurement (300 yards per pound) indicating the degree of fineness of the yarn from which the threads of the line were made.

[3]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

During the mid-1890's, gasoline boat engines were developed (Scofield, 1956), which would have a profound effect on the expansion of ocean sport fishing on the west coast. After the turn of the century a steadily increasing number of boats began to shift from sail and oar power to gasoline engine power.

One of the most important developments in ocean fishing tackle was the invention of the star-drag reel. The first reel (Fig. 1) of this type with slipping clutch (internal drag) and irreversible handle was patented by Edward Vom Hofe and Co. in 1902 for big game fishing off Catalina (Major, 1948; Melner and Kessler, 1972). After about 1913, the Vom Hofe star drag and other similar reels began to replace the early knucklebusters (Major, 1948; Reiger, 1973), but apparently they were mostly used by big game fish anglers and still quite expensive. In a 1919 catalogue, prices for the Universal Star (Vom Hofe) in sizes 2/0 to 9/0 ranged from $57.50 to $75.50 each (Melner and Kessler, 1972).

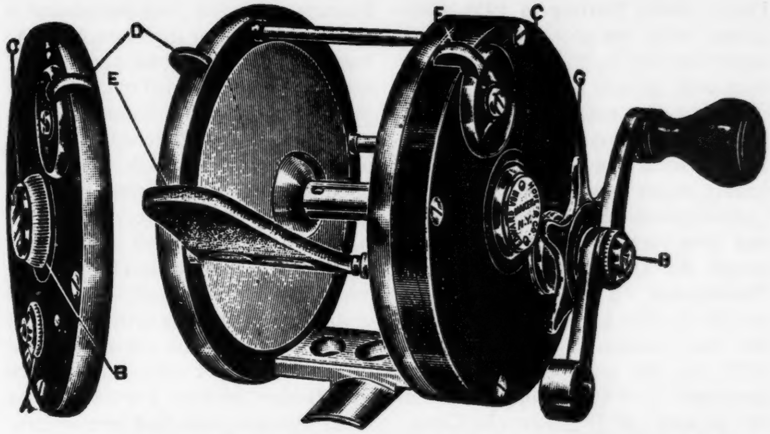


Figure 1.—Vom Hofe & Company's "Universal Star," forerunner of today's star-drag reel design, as it appeared in a 1919 catalog (E=removable leather thumb pad, F=free-spool lever. G=star drag). Taken from *Great Fishing Tackle Catalogs* edited by Samuel Melner and Hermann Kessler. Commentary by Sparse Grey Hackle. ©1972 by Samuel Melner and Hermann Kessler. Introduction and commentary ©1972 by Alfred W. Miller. Used by permission of Crown Publishers, Inc.

The 1920's marked a turning point in ocean fishing with the introduction of public sportfishing boats and fishing barges in southern California (Major, 1948; Van Deventer, 1926; Sadler, 1928). In general, a sportfishing boat or party boat[4] provides fishing space to the public for a fee and operates on a scheduled basis as opposed to charters and rentals where the boat itself is hired for the exclusive use of one or more anglers. Barges are essentially immobile sportfishing boats reached by shuttle launches from shore. With these new facilities, open ocean fishing became available to the general public.

In the 1930's, live-bait fishing and public sportfishing (Fig. 2) became established in southern California, while ocean pleasure fishing was just beginning or already underway in

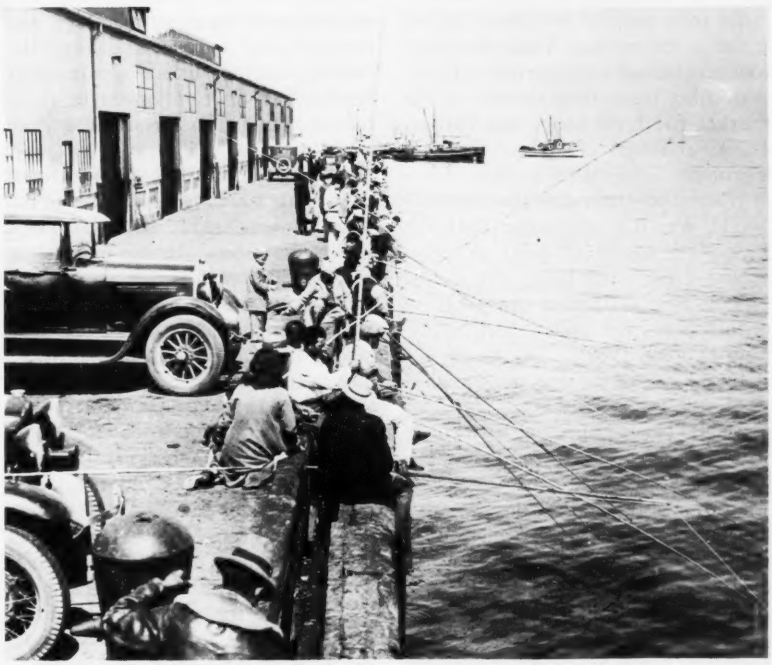


Figure 2.—Pierfishing for mackerel at Monterey, Calif., in 1931. Note long bamboo poles (no reels) and thick lines. Mass-produced, low-cost star-drag reels came on the market about 4 years after this photo was taken. (Photo courtesy of California Department of Fish and Game.)

[4]In this report the term "sport fishing boat" has been substituted for, and is synonymous with, "partyboat." Use of the latter term has been discouraged by members of the recreational fishing industry.

northern California (Croker, 1938b; Davis, 1949). Starting in 1935, California boat operators who carried anglers for hire were required by law to keep daily records of their catch.

During the mid-1930's, American reel manufacturers introduced moderately priced, mass-produced, high quality, revolving spool reels (star-drag type) to middle and low income people, and these reels soon came into widespread use (H. Henze, Penn Reels, Philadelphia, Pa., pers. comun.). Although the first spinning (fixed spool) reel was introduced from France in 1935, by the time a market was developed in 1939, the supply was cut off because of the war (McClane, 1974). Braided nylon fishing line made its appearance around 1939 (samples were exhibited at the San Francisco World's Fair), and it later came into limited use during the war years (A.W. Agnew, Sunset Line and Twine, Petaluma, Calif., pers. commun.). This early nylon line stretched badly, and at the time, no one knew how to eliminate or reduce the stretch factor. In general, bamboo was the most popular rod material, although in 1936, tubular metal rods made of beryllium copper came on the market. These beryllium rods resisted saltwater corrosion better than other metal rods already on the market for freshwater use (Moss, 1976), although corrosion was still a problem.

When the United States entered World War II in December 1941, the U.S. Navy closed all ports to sportfishing. Later a few boats with special permits were allowed to operate from certain ports, but under strict regulations (Young, 1969).

By the end of the war, most anglers were still using cane rods, star-drag reels, and twisted linen line with gut or wire leaders, but important developments in tackle were already underway. Many reels were now equipped with lightweight plastic spools which made it much easier to cast light lures and live bait using cuttyhunk line. Also, by this time, the gear-in-mesh feature was available on most reels. Prior to this invention it was very easy to strip the gears of a reel if the angler threw it into gear while a fish was running with the line.

An important new product, monofilament nylon line, was introduced in 1946. Although the first monofilament line was waterproof (did not rot) and was lighter than braided nylon or linen line, it was stiff and difficult to use as a main line. It also stretched badly and played havoc with plastic spool reels, bursting them under pressure. Later, many improvements were made that cut down on the stretch, and casting lines were made softer and limper. Soft monofilament was finally introduced to the west coast in the early 1950's, but it did not begin to outsell braided linen line until the early 1960's when spin fishing became popular in salt water. Spinning reels had been reintroduced about the same time as monofilament line (circa 1946), but these were mainly designed for freshwater fishing. The early spinning reels were trouble-prone and did not work well with braided line which was still popular for ocean fishing in the 1940's.

An important advance in rod building occurred in 1948, when fiberglass rods were introduced, and solid, hollow, and wooden core models became available (Major, 1948). The advantage of fiberglass was that it was flexible and tough, excellent for casting, and did not take a permanent bend or "set" after prolonged use as did bamboo or hardwood rods, or rust like metal rods.

Also, in the late 1940's, the first fiberglass boats were made available to the public. Fiberglass enabled boat builders to mass produce one-piece hulls with a minimum of skilled labor, and in following years this material would become a standard in the pleasure boat field (Whittier, 1976). Advancements in welded and riveted aluminum hulls also helped to make aluminum a popular boat-building material. These new materials made fishing skiffs strong yet light and portable, and relatively maintenance free.

Another postwar development was the introduction of outboard engines with forward-neutral-reverse gearshifts. These soon replaced the old direct drive outboards, making small boats more manageable, safer, and simpler to operate. Soon afterward manufacturers offered cable-operated remote-control steering so one could operate the motor from up forward, giving the boat better stability and the skipper better forward visibility (Whittier, 1976). These developments, as well as the many other improvements in boat and engine designs that followed after the war, including the introduction of electric starters, radio-telephones, fathometers, radar, and other electronic equipment, had a great influence on the expansion of the recreational boat fishery in California.

In 1950, soft monofilament fishing line was introduced on the west coast. Soon most leader materials were discarded in favor of tying the hook directly to the monofilament line. This made casting small baits and lures easier and caused a boom in the lure business (Agnew, Sunset Line and Twine Co., Petaluma, Calif., pers. commun.; Cannon, 1964). Also, during this time, fiberglass rods were quickly replacing the old cane rods. Moderately priced, quality spinning reels were introduced in 1953, and these reels soon became popular in freshwater fishing, and later (the 1960's) in saltwater fishing. The spinning reel, or fixed-spool design, eliminated the main cause of line backlashes, permitted the use of very light lures and baits, and perhaps most important, made the art of casting relatively easy to master for novice anglers.

In the late 1950's, the Coast Guard enforced stringent regulations for passenger boats (Frey, 1971), and the following years would see a marked decrease, followed by a leveling off, in the number of active sportfishing boats (Young, 1969), and a trend, especially in southern California, toward larger, faster, and more comfortable boats designed for offshore and long-range fishing trips. Many of the larger southern California sport boats were built and launched during this period (Young, 1969).

In the 1960's, the combination of spinning reels, fiberglass rods, and monofilament nylon line became established in saltwater fishing in California. On the west coast, monofilament line came into widespread use, outselling braided line (Agnew, Sunset Line and Twine, Petaluma, Calif., pers. commun.). By the mid-1960's, fiberglass had dominated the rod market.

Today, nylon monofilament line is still the most popular line, and is used on both spinning and revolving spool reels. Spinning gear is especially popular for the many small-to-medium-sized game fishes found in California's inshore waters. Revolving spool reels are enjoying renewed popularity largely due to refinements in reel designs. Some of the newer reels have an internal centrifugal brake system as well as an external spool tension control that allows the angler to cast lures and baits with monofilament line without line backlashes—the main drawback of old revolving-spool reels. Spinning tackle is now common on southern California live-bait sportfishing boats, although the combination of conventional (revolving-spool) reels and monofilament line is widely used, and is also preferred for ocean salmon trolling and sturgeon fishing in northern California, and jigging for some of the larger game fish in southern California.

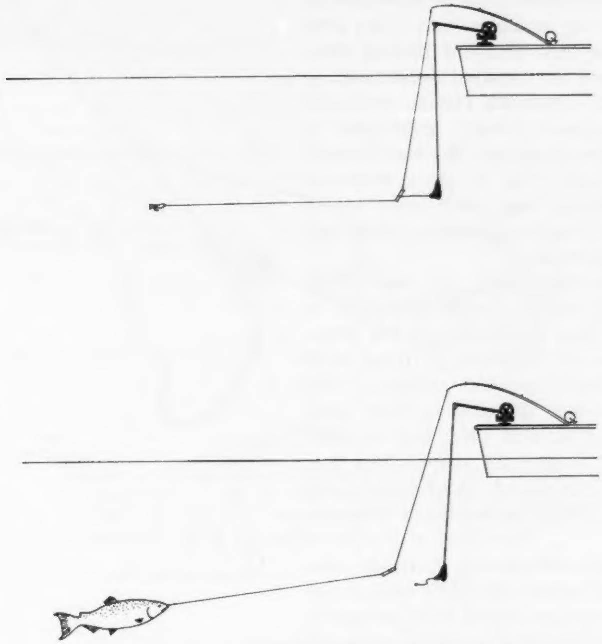


Figure 3.—The downrigger allows an angler to fish a bait or lure at accurately controlled depths using light tackle. When a fish strikes, the angler's line is released from the downrigger sinker and line.

Braided lines (nylon and Dacron) are generally reserved for big-game trolling and offshore bottom fishing where heavy duty conventional reels and rods are used. A new type of small diameter braided Dacron line has recently been introduced and is gaining in popularity in southern California. It has good abrasion resistance and low stretch (7-8 percent as compared with nylon line with 20-25 percent stretch).

The tubular fiberglass rod is still the standard in California sport fishing; however, a new type of rod made from graphite was introduced around 1973. Graphite rods are extremely light and ultrasensitive, yet very strong, though approximately one-third smaller in diameter than comparable fiberglass rods. At this time, however, graphite rods are still quite expensive.

Finally, the downrigger (Fig. 3), used for deep-water trolling, is showing up on an increasing number of private sportfishing boats in California. This device allows the angler to fish at a bait at accurately controlled depths with light or medium tackle and land a fish without the hindrance or loss of the sinker. The downrigger is clamped to the side or stern of the boat and consists of a short rod and hand-cranked or electrically operated metal drum loaded with stainless steel wire weighted at the end with a heavy cannonball or diving sinker. The angler's unweighted line is attached to the weighted downrigger line by a metal sinker release or release clip, then lowered to the desired depth. When a fish strikes the bait, the angler's line is released, allowing him to fight and land his fish on the free line.

Fishing Technique and Tackle Changes

The following are just a few examples of specific marine recreational fisheries in California that have been affected by developments in sportfishing tackle and fishing methods. No doubt other fisheries have been affected as well. These examples are also used to document present methods and tackle.

San Francisco Area Striped Bass Fishery

Up until the mid-1950's, striped bass, *Morone saxatilis,* fishing methods in San Francisco Bay had remained essentially the same for about half a century—still-fishing with bait and near-surface trolling with artificial lures. But in the summer of 1957, a collapse of the ocean salmon fishery brought salmon sport fishing boats into the bay to fish for striped bass in deep water using the new technique of deep-line trolling with 3-pound (1.4-kg) sinkers and sinker releases (Chadwick, 1962). Many bass were caught, that year off Alcatraz Island, and subsequently in other areas in upper San Francisco Bay. From 1957 to 1959, most fish caught in the upper bay were taken by deep-line trolling. Furthermore, a winter fishery developed around 1958 when anglers discovered

that striped bass could be taken during the herring spawning runs. They used both the new deep-line trolling technique and the standard surface trolling method. Chadwick (1962) concluded that because fishing techniques in upper San Francisco Bay had changed so radically (Fig. 4), the commercial sport fishing boat catch could not be used to measure changes in abundance of striped bass.

From the early to mid-1960's, another major change occurred in striped bass methods with the introduction of live bait drifting with anchovies, *Engraulis mordax*. Only one live-bait sportfishing boat operated in 1962 and 1963, but by 1965, live-bait fishing for striped bass was firmly established (McKechnie and Fenner, 1971; Chadwick and Albrecht, 1965).

Ocean surf-casting methods also changed in the mid-1960's when it was discovered that striped bass gathered in feeding schools at certain areas off ocean beaches, at which time they would readily take artificial lures cast from shore (Miller, 1974). Until then, practically all surf-caught bass were taken with bait, usually clams. According to Frey (1971), by 1966 nearly all striped bass surf anglers had switched to metal and plastic artificial lures. This changeover also affected the catch along ocean beaches of redtail surfperch *Amphistichus rhodoterus*, which previously had been taken incidentally on hooks baited for striped bass. When anglers switched to lures cast out and quickly retrieved, redtail surfperch (which are seldom taken by this method) occurred much less frequently in the catch (Frey, 1971).

Today in San Francisco Bay, live-bait fishing is the primary method used by striped bass sportfishing boats at the height of the summer and fall seasons. Anchovies and shiner perch *Cymatogaster aggregata*, are used as bait. Boats repeatedly drift over areas where an abrupt change in depth occurs and when the current is running swiftest. In early spring, however, some will troll deep, using either single lines rigged with plastic skirt lures ("hoochies") or tandem spreader rigs baited with artificial lures (spoons, plugs, bug-eye

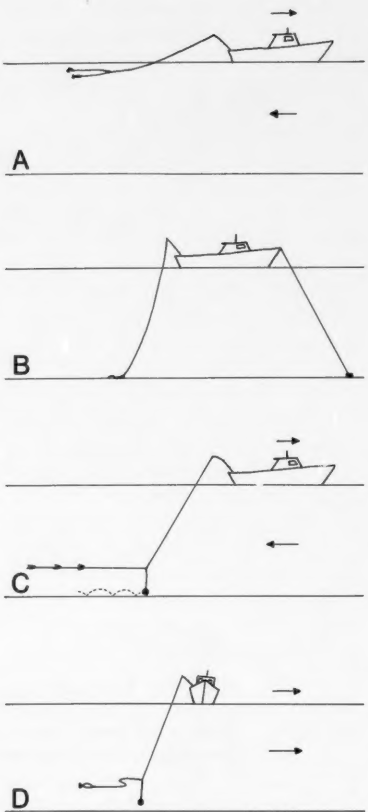


Figure 4.—Over a span of about 8 years, striped bass sport fishing boat methods have changed from (A) near-surface trolling and (B) bottomfishing, to (C) deep trolling and then (D) deep drifting with live bait.

jigs). Among the advantages of live bait fishing on passenger boats, as opposed to deep-line trolling (still a very effective method), are that many lines can be fished at a time, and more anglers can be accommodated per trip. The method is also relatively simple for the novice angler (C. Anfrinson, Captain, fishing vessel *Bass Tub III*, pers. commun.).

In San Pablo Bay and adjacent bays, rivers, and sloughs and up into the Delta, bait fishing remains the most widely used method in fall and winter. Staghorn sculpin *Leptocottus armatus*, mudsuckers *Gillichthys mirabilis*, and bay shrimp *Crangon* sp., are used as bait. During the summer, anglers will sometimes troll artificial lures.

Private boat and rental skiff anglers throughout the bay system conduct both surface and deep-line trolling for bass as well as plug casting and bait fishing. Shore anglers cast baits and artificial lures from piers, jetties, banks, and beaches. Some fly-fishing is done in the relatively shallow, quiet waters of the bay.

Boat rods and revolving spool reels are generally used for deep trolling and deep drifting with live bait, while both spinning and conventional tackle are used for surface trolling and casting. Fiberglass surf-casting rods range up to 12 feet (3.7 m) long. Line strengths vary with fishing method, usually anywhere from 12 to 20 pound test monofilament for casting, to 40 pound test or heavier for deep-line trolling where cannonball sinkers (1/2- to 1-pound or 0.2- to 0.5-kg) are used. In deep-line trolling, some sportfishing boats use heavy duty monel wire for the main line, where 2- to 3-pound (0.9 to 1.4-kg) sinkers are needed to carry the long (up to 12 m) monofilament leader to the desired depth.

Sturgeon Fishing in San Francisco Bay

Sturgeon fishing, prohibited by law in 1917, was opened to sportfishing in 1954; the fishery centered in the San Francisco Bay estuary system. The most common species, the white sturgeon, *Acipenser transmontanus*, reaches a length of 20 feet (610 cm) and a weight of 1,800 pounds (816.5 kg) (Squire and Smith, 1977). A size limit of 40 inches (102 cm) was established with a one-fish bag limit. Initially, snagging by trollers seemed to be the only effective method, but trolling for sturgeon was prohibited by law in 1956 (Miller, 1972). Relatively few fish were taken until 1964 when it was discovered that bay shrimp, *Crangon* sp., was a very effective bait (McKechnie and Fenner, 1971). With this discovery, yearly sport fishing boat catches jumped from 3 sturgeon in 1963 to 2,400 in 1967—a striking example of the effect of a new fishing technique on

a fishery. There seems little doubt that angler efficiency increased over this period.

In succeeding years, bottom fishing for sturgeon became increasingly popular in the San Francisco Bay area, with most angling taking place from sportfishing boats and skiffs (private and rented) in San Pablo and Suisun Bays from fall through early spring. In these areas the standard equipment is a 7- to 8-foot (2.1- to 2.4-m) boat rod with a flexible tip, and conventional star-drag reel loaded with about 300 yards (274 m) of 40- to 50-pound test monofilament line. Most anglers use one of the commercially available sturgeon rigs that include a wire or heavy sleeve, and hooks. The bait is usually live or freshly-dead bay shrimp (Fig. 5), although mudsucker, *Gillichthys mirabilis*, and ghost shrimp, *Upogebia pugettensis* and *Callianassa californiensis*, have also been used in recent years. In fact, the use of callianassid bait has increased dramatically since about 1976, and it is possible that ghost shrimp, particularly *C. californiensis*, may be an even more effective bait for sturgeon than bay shrimp.

Sinker weights vary with the strength of the current. The method is to locate a known or suspected sturgeon ground, then anchor. After dropping a baited hook over the side, line is payed out and the rod tip watched closely. After the first light tap, a few more feet of line is payed out. Usually when the second tap is felt, the angler sets the hook. A modest fishery takes place in south San Francisco Bay, where anglers use methods and tackle similar to those in San Pablo and Suisun Bays.

A separate fishery also exists in upper San Francisco Bay during the herring (*Clupea harengus*) spawning runs that occur from about January to March. At this time, sturgeon are known to feed on herring eggs around the Sausalito and Tiburon Peninsulas, where, during the height of the runs, sturgeon are caught by shore and boat anglers (Fig. 6). This fishery developed over the past 8 years, growing from a handful of anglers in 1970, and increasing rapidly since 1974 as more anglers learned of the availability of sturgeon in these areas and the techniques to catch them (L. Green, San Bruno, Calif., pers. commun.). The fish are caught bottom fishing close to shore, often during swift-running incoming tides. Instead of the standard grass shrimp, herring fillets or wads of herring roe are used for bait. In the herring spawning areas, the sliding sinker rig is used over sand or mud bottom, while over rocky bottom the weight is attached to a short length of lighter line which is tied to a swivel about 60 cm above the hook.

Recently, snagging again became a problem, especially during times when sturgeon would congregate to feed on herring spawn. Reportedly, some anglers were casting out heavy lures and snagging fish on the retrieve. In 1978, this type of snagging became illegal, and anglers are now required to

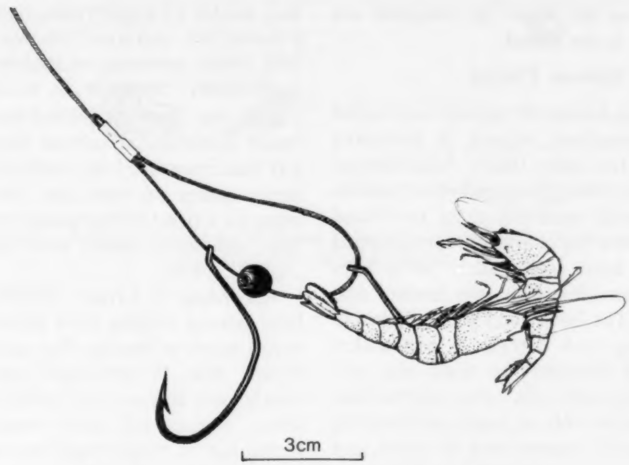


Figure 5.—Discovery in the early 1960's of bay shrimp, *Crangon* sp., for bait revolutionized the sturgeon fishery in San Francisco Bay. The terminal end of a typical rig is shown (one hook left unbaited to show hook type).

Figure 6.—Landing a white sturgeon in San Francisco Bay. In recent years, Bay anglers have developed effective methods for catching sturgeon on the herrring spawning grounds near the Golden Gate Bridge.

return to the water all sturgeon not hooked in the mouth.

Ocean Salmon Fishing

Ocean fishing for salmon was started by recreational anglers in Monterey Bay in the early 1880's. According to Scofield (1956), they trolled for salmon from small sailboats using two hand rods and a line over each side equipped with a hook and leader. Some lines were provided with two leaders and hooks. The leader was about 30 feet (9 m) long and carried a lead sinker midway between the main line and lure. Up until this time, salmon had been taken only in rivers and bays by commercial netters and in rivers and streams by anglers using fly-fishing or freshwater baitcasting tackle.

By 1893, the troll-line sport fishery had become well established in the Monterey Bay area. Anglers fished from sailboats or rowboats using "stout lines and hooks attached to flyrods or simply fished by hand . . ." (Smith, 1895). Sardine was the principal bait. In 1893, a writer for *Forest and Stream* (predecessor to today's *Field and Stream* magazine) reported fishing for salmon in Monterey Bay with a trolling rod, multiplying reel, and linen line (cited by Smith, 1895).

By 1902, anglers were trolling for salmon in the ocean just north of San Francisco. According to old newspaper reports, they trolled from launches, fishing the area between Tennessee Cove and Bolinas Bay, Marin County, some using artificial lures (Neal, 1977). Around the same time in Monterey Bay, anglers apparently were still relying on sardines, *Sardinops sagax*, for bait, and spoons were only rarely used (Jordan and Evermann, 1902). They would use a 30-ply line and a 3- to 5-pound (1.4- to 2.3-kg) sinker attached to a lighter 24-ply line, 6 m above the hook. About 150 feet (46 m) of line would be let out and the bait fished 6-15 m below the surface, trolled at about 4 miles per hour (Jordan and Evermann, 1902).

By 1908, ocean salmon anglers in central California were beginning to use lighter, more sporting tackle for salmon. That year, large catches of salmon were reported in Monterey Bay, landed by anglers using light rods, 9-thread line, and size 7/0 hooks baited with smelt, anchovy, or sardine (Holder, 1908). In 1908, a writer for *Forest and Stream* reported that while "most professional salmon fishermen [off San Francisco] use sardines and a heavy sinker on thick line, the amateurs use a new trolling spoon on a light line, and secure many more strikes" (A.P.B., 1908).

According to Croker (1938b), very little salmon angling took place in the ocean north of Bodega Bay until after World War II, although sometimes north coast commercial trollers would allow anglers on their boats. The technique of "mooching" for salmon was introduced to California at Humboldt Bay in the late 1930's or early 1940's, when there was a great influx of anchovies into the Bay (D. Gotshall, Calif. Dep. Fish Game, Monterey, Calif., pers. commun.). This method apparently originated in the Seattle, Wash., area, developed by Elliot Bay anglers around the turn of the century (Haw et al., 1967).

Humboldt Bay mooching involves drifting a bait (usually anchovy) close to the bottom on an incoming tide, repeatedly lifting the bait up at an angle, then letting it drop back again. The action is also imparted by varying the boat speed (motor or oar power), to help the drift when the current is running swiftly. Mooching rods are usually longer, lighter, and more limber than conventional rods used in ocean trolling for salmon, and are combined with revolving spool reels. The line (after about 1950, nylon monofilament) is usually weighted with a light, crescent-shaped sinker.

In the San Francisco area in the 1930's, metal sinker releases (the spring-loaded type similar to that used today) had already come into use. It is not known exactly when this device was introduced in California, but apparently it was first used with window sash weights, then cannonball sinkers. It soon became part of standard trolling tackle. During the 1930's, San Francisco salmon trollers would use spoons in spring, then later in the season switch to bait (anchovies, sometimes sardines). They used primitive long-shank commercial salmon hooks with no eye, and these were tied directly to the cuttyhunk line, which anglers would often mark with paint or nailpolish to better gauge the fishing depth (A. W. Agnew, Sunset Line and Twine, Petaluma, Calif., pers. commun.). After the war before monofilament nylon came into use, piano wire was used as leader material (E. Neal, *San Francisco Examiner*, pers. commun.)

During the 1950's, ocean salmon fishing increased phenomenally, and no doubt the development of more powerful and dependable boat engines and improvements in boat design had much to do with the expansion of the sport (Wendler, 1960). Anglers could reach fishing grounds that were previously unsafe or out of reach. Availability of moderately priced, quality fishing tackle—fiberglass rods, monofilament line, and trouble-free fishing reels—also played a part in the expansion of ocean salmon fishing.

Today, sport fishing for salmon is conducted all along the central and northern California coast from Avila Beach to Crescent City. Most fishing north of Fort Bragg is conducted from skiffs, although commercial sport fishing boats are available seasonally at Eureka, Trinidad, and Crescent City. The majority of salmon sport boats operate out of the San Francisco Bay area. Both chinook, *Oncorhynchus tshawytscha*, and coho, *O. kisutch*, salmon are taken, with chinooks dominating the catch south of Fort Bragg and cohos entering the catch more frequently to the north. Although the tackle has changed considerably over the years, the method of fishing is basically the same used back in 1902 at Monterey Bay—trolling whole fish baits from 6 to 18 m below the water's surface, depending on where the fish are feeding.

Offshore of the Golden Gate Bridge, where the most consistent salmon runs occur, the standard tackle consists of a conventional fiberglass boat rod (7-8 feet or 2.1-2.4 m) combined with a medium-sized star-drag reel loaded with about 200-250 yards (183 to 229 m) of 20 to 30 pound test nylon monofilament or Dacron line. Many anglers

use a metal sinker release and cannonball weights of 1-3 pounds (0.5-1.4 kg). Plastic diving planes are sometimes used but as yet are not as common as the sinker release rig. An increasing number of boats are equipped with downriggers to carry the bait to the desired depth. Standard bait is fresh-frozen anchovy, though herring is also used. The bait is usually threaded on one of the commercially available bait holders (crowbars, easy-baiters). A sliding two-hook rig is used along the north coast, as are mooching rigs and the combination of a #2/0 hook and crescent or torpedo-shaped sinker. Some anglers attach a spinning "flasher" or wobbling "herring dodger" (both shiny metal attractors) between the sinker and bait (Fig. 7). Most north coast sport fishing boats use the flasher or dodger rig; it is not as common on San Francisco boats. Artificial lures (particularly spoons) are in use, especially from Monterey south to Avila Beach, but in general these run a distant second to fish bait.

Boats troll over a known fishing ground at about 2 to 5 miles per hour with lines fished at slightly different depths to avoid tangles. Coho salmon are taken nearer the surface than chinooks, with baits fished usually no deeper than 6 or 9 m below the surface.

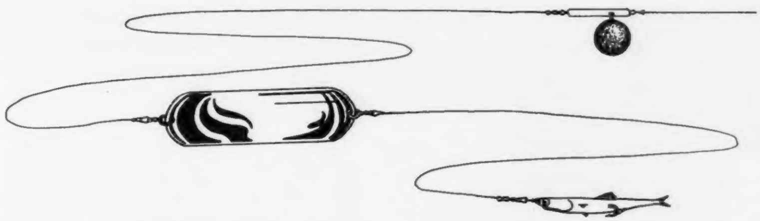


Figure 7.—Salmon trolling rig showing cannonball sinker and release, metal attractor, and rigged anchovy.

Figure 8.—Sport boat seining for sardines outside Long Beach Harbor, 1928. In the early days of southern California live-bait fishing, sport boats netted their own bait before picking up passengers (long bamboo poles rest against cabin). (Photo courtesy of California Department of Fish and Game.)

Southern California Live Bait Fishing

As mentioned earlier, live-bait fishing from public sport fishing vessels was introduced in southern California in the 1920's. Initially, trolling was the principal method, but as early as 1925 some boats were using live bait. These early "live-bait boats" would go out on a scheduled basis every day, but were primitive and offered anglers little in the way of comfort (Davis, 1949). Bait was kept in barrels which had to be replenished every few minutes with buckets of fresh seawater (Hull, 1973). Sardines, the principal live bait, were netted prior to the fishing trip (Fig. 8).

Figure 9.—Live-bait fishing off Rocky Point, southern California, 1938. (Photo courtesy of California Department of Fish and Game.)

In the 1930's, the use of live bait for both bait and chum became established (Fig. 9). By the mid-1930's, a few boats began to specialize in catching and supplying live bait to others, and the live bait industry was born (Hull, 1974). Also, new live bait tanks were developed that circulated a continuous flow of pumped water to keep the bait in good condition. Standard tackle was

Figure 10.—Deck hand gaffs a bluefin tuna on a 1937 fishing trip off Catalina Island. In the late 1930's, southern California live-bait anglers fished with hefty cane rods, star-drag reels, and linen line using sardine for bait and chum. (Photo courtesy of California Department of Fish and Game.)

Figure 11.—Live-bait fishing off southern California in the 1970's. Modern sport boats such as this one are faster, safer, and more comfortable than those of prior decades, and are outfitted with sophisticated electronic fish-finding, radio, and navigational equipment to more efficiently locate concentrations of fish.

a bamboo rod, star-drag reel, twisted linen line (cuttyhunk), and a gut or wire leader (Fig. 10).

In the years that immediately followed World War II, most sport fishing boat anglers were still using medium star-drag reels, Calcutta bamboo poles, twisted linen (and some twisted nylon) line (27- to 30-pound test), and live bait hooks in sizes 1/0 through 4/0, depending on target fish size. Sinkers (most often the torpedo-type), were used for California halibut, *Paralichthys californicus*, and other bottomfishes. Many anglers were now using plastic spools on their reels to make it easier to cast live baits. Leader material was either gut or piano wire. Heavy stainless steel wire was often used for jigging, and some anglers, nicknamed "feather merchants," would bring lighter tackle and fish with feather jigs. By the late 1940's, anchovies had pretty much replaced the hardier sardine as live bait, as the latter were getting too difficult to obtain. Sometimes queenfish, *Seriphus politus*, was used as live bait for kelp bass, *Paralabrax clathratus*, and California halibut.

During the 1950's, soft monofilament nylon line began showing up on sportfishing boats, and fiberglass rods were replacing the old cane rods. New high-speed retrieve reels (star-drag type) were introduced in 1959, and became popular for yellowtail, *Seriola dorsalis*, jigging (H. Heerse, Penn Reels, Philadelphia, Pa., pers. commun.).

In the 1960's and 1970's, fiberglass rods and nylon monofilament line came into widespread use on sportfishing boats (Fig. 11). Today, live bait anglers usually use light to medium action fiberglass rods, generally from 6½ to 7½ feet (2.0 to 2.3 m) long and with a fast taper. These live-bait rods are designed to be strong yet light, with tips flexible enough to cast a small live anchovy on an unweighted line. The choice of medium or light tackle depends on the species sought, and often how crowded the boat is. If many anglers are fishing at close quarters, light tackle is usually discouraged. Open faced spinning or conventional star-drag reels are used, loaded with about 250-300 yards (229-274 m) of 15- to 20-pound test monofilament line. Today, live-bait hooks are much smaller than those used throughout the postwar years and are of the short-shank O'Shaughnessy type with point bent toward the shank (Garrison and Rice, 1972). Generally, hook sizes range from 1 through 6, and the hook is tied directly to the end of

the line. If the fish are not near the surface, a lightweight rubber-cored sinker is attached to the line about 3 feet (91 cm) above the bait (Fig. 12). Live bait is still predominantly anchovy, which is hooked upwards through the gill collar or through the snout. Larger baits and larger hooks (sizes 1/0 to 4/0) are used for bigger game such as large white seabass, *Cynoscion nobilis,* yellowtail, and large kelp bass. Live squid (*Loligo* spp.), hooked through the tip of the mantle, is prime bait for the above species. Pacific mackerel, *Scomber japonicus,* usually hooked through the snout, is also used as live bait for these larger fish. Queenfish, hooked under the breastbone, is still popular for large kelp bass.

A sport boat will arrive at a known fishing spot, such as the seaward side of a kelp bed, and begin to chum slowly with live anchovies, while making a circle about 46 m in diameter. If fish begin to break the surface within the circle, the captain will anchor the boat and continue chumming (Fig. 13). Anglers then cast or ease their baited hooks over the side, set their reels in free spool or open bail, and allow the bait to move relatively free in the water. When a game fish takes the bait, it is permitted to run a short distance before the reel is put in gear and the angler sets the hook.

Offshore Bottomfishing in Northern California

For many years, offshore bottomfish have been an important staple of California marine recreational fishing. Rockfish (*Sebastes* spp.) are the principal species in the bottomfish catch, although others, such as lingcod, *Ophiodon elongatus,* cabezon, *Scorpaenichthys marmoratus,* and flatfishes, also are landed. Approximately 55 species of rockfish occur in California waters, and 29 of these are known to occur in the northern California sport boat catch (Miller and Gotshall, 1965). Since the early 1960's, rockfish have ranked first in numbers of fish taken by sport boat anglers, and between 1972 and 1975 they composed over one-half of the annual statewide catch (Pinkas, 1977). Rockfish are important in both northern and southern California, and are particularly valuable in areas where other game fishes show up less predictably or only seasonally.

Offshore bottomfishing for sport has been conducted in California since before the turn of this century. According to early newspaper reports, in the late 1870's and 1880's there were sportfishing excursions during summer out of Humboldt Bay to bottom fishing grounds off False Cape and Cape Mendocino (Wainwright, 1965). Two steam tugs, each accommodating about 30 passengers, operated out of the Eureka area; and tickets for a fishing trip were sold to anglers for $2.00 each (Wainwright, 1965). Rockfish composed the bulk of the catch, though Pacific halibut *Hippoglossus stenolepis,* and true cod (*Gadus macrocephalus*) also were taken. The reports do not go into detail about tackle, but the anglers apparently used handlines, the primary method used for ocean bottomfish in California for about 50 years thereafter.

By the 1930's, rod and reel was beginning to appear in the ocean bottomfishery, although most fishing was still done with handlines. In 1933, a pleasure fishing trip out of Princeton was described by Buchanan (cited by Young, 1969). According to his report, 14 anglers boarded a 30-foot (9.2-m) long fishing launch and went out one-half to three-quarters of a mile offshore before dropping lines. Only two anglers used poles, the rest used handlines with three hooks baited with sardine, the whole rig weighted with a 2-pound (0.9-kg) sinker. Black rock

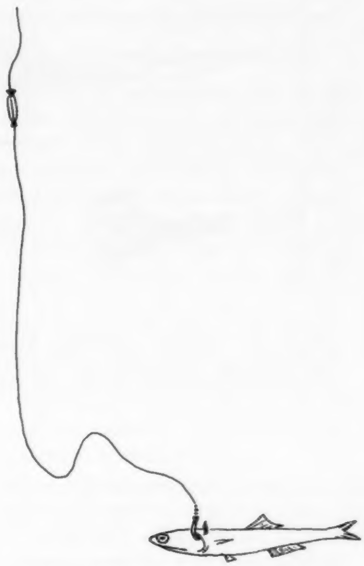


Figure 12.—Southern California live-bait rig. Rubber-cored sinker (above bait) is used if fish are not feeding near the surface.

Figure 13.—Live-bait fishing from a southern California sport fishing boat.

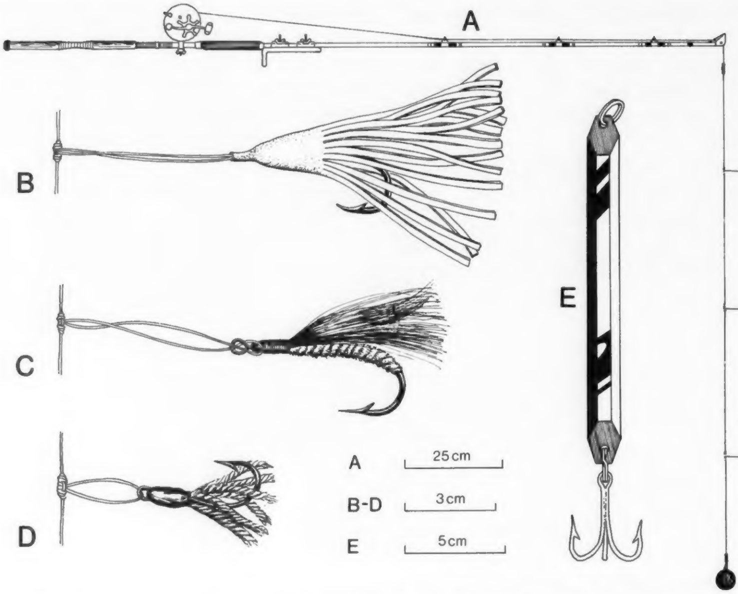


Figure 14.—Northern California bottomfish tackle (1970's): (A) Boat pole with star-drag reel, deck plate, multijig rig, and cannonball sinker; (B-D) variations in rockfish jig designs; (E) chrome "hex" jig used for lingcod and large rockfish.

fish (assume *S. melanops*) dominated the catch, although flatfishes and other species of rockfish were also taken.

In Monterey Bay, offshore bottomfishing up until the early 1940's was done almost exclusively with cotton handlines, which were supplied to anglers at the onset of the trip (F. Arcoleo, retired sport boat captain, Monterey, Calif., pers. commun.). Each handline was about 91 m long, rigged with two dropper lines and 5/0 hooks baited with salted sardine, and weighted with an old railroad spike. Around 1941, Monterey sport boat anglers began using bamboo poles, star-drag reels, and twisted linen (cuttyhunk) line. The standard method was baitfishing with sardine, although some anglers (usually the more experienced ones) used chrome hexagonal jigs for blue, olive, and yellowtail rockfish. These 24-ounce (0.68-kg) "hex" jigs were, and still are, very effective but it takes skill to avoid snagging and losing them on the bottom.

In the late 1940's, fiberglass rods began showing up on the sport boats and squid was rapidly replacing sardine as bait. The first fathometers also came into use in the late 1940's, but they were generally not accepted until after 1955 when more sensitive models became available. The new monofilament nylon line also took a while to be accepted because even though it was lighter and drifted less than linen line, it stretched badly and damaged plastic reel spools that were used in bottomfishing at the time. About a decade later, when metal spools were used, and line manufacturers were able to cut down on line stretch, nylon monofilament replaced linen line in the Monterey fishery.

Around the time nylon monofilament line was being accepted, an important change in terminal tackle occurred with the introduction of the multiple jig rig for rockfish. These rigs, which vary in design from port to port and are variously called "cod flies," "shrimp flies," "wonderlures," etc., consist of a 5-foot (152-cm) nylon monofilament leader with from three to five hooks on short dropper loops—the hooks decorated with brightly colored yarn, synthetic fibers, or plastic skirts (Fig. 14). According to sport boat captains in Monterey Bay, when these rigs were introduced in the Monterey area around 1957, the boat that first used them consistently caught more fish than other boats fishing in the same area at the same time. Soon afterward, other sport boat operators in the Monterey Bay area began to use the new multijig rigs. According to Miller (Calif. Dep. Fish and Game, Monterey, Calif., pers. commun.), rockfish landings increased during this period, especially catches of schooling pelagic types such as blue, yellowtail, widow, and olive rockfishes. In this instance, the new type of terminal tackle may not only have affected catch-per-unit-of-effort, but species composition of the catch as well. Also, in the late 1960's and early 1970's spinning gear became available on the Monterey boats so that anglers could fish with feather jigs in case a surface feeding school of blue or yellowtail rockfish was found.

The multijig rockfish lures are now commonly used throughout most of northern California, along with the standard combination of fiberglass boat rods, heavy duty star-drag reels, and nylon monofilament and braided Dacron lines testing at 40-60 pounds. The multijig rigs are fished successfully with or without bait (squid or cut anchovy). Sinker weights vary from 8 ounces to 2 pounds (from 0.2 to 0.9 kg) or more. The hexagonal chrome jigs, in use before World War II, are still commonly used, especially for lingcod, which are also taken with single hook rigs baited with small live rockfish and live squid when available. Recently, other types of jigs, some very similar to the "candy bar" types used on southern California sport boats, have been introduced to central California bottomfishing.

Even if it is assumed that the fishing power of the terminal tackle itself has not changed, ongoing improvements in electronic equipment and boat and engine design since the 1940's have obviously enabled boats to fish in deeper water and travel to new bottomfish grounds farther from port. Ultrasensitive fathometers have helped to

locate new reef areas and concentrations of fish with less search time and greater accuracy. The switch from handlines to rod and reel and lighter line also made it easier to fish in deeper water. Today boats are able to fish in water to 183 m deep, whereas handline depth averaged about 37 to 46 m, and early rod and reel depth about 73 to 92 m.

When handlines were used, boats could only fish in shallow water because the heavy lines drifted badly in the current an even with relatively short lengths of line, there was a constant problem with on-deck line tangles between pulls, which cut down on actual fishing time. On some boats, large wooden reels that clamped to the deck rail were used to haul up line, but not all anglers used them, and they were cumbersome and offered little in the way of sport. With rod and reel came lighter line (first linen and then even lighter nylon monofilament and braided Dacron), and soon line drift was no longer much of a problem. Since excess line was retrieved on the reel spool, the major cause of on-deck line tangles was eliminated. Other developments over the past 10 years, such as deck plates[5] and reel handle extensions, have also made it easier to crank up fish and heavy sinkers from the depths.

Discussion

It is often said that most of the fish are caught by a small minority of anglers—the ones with the most experience and skill. Although these two factors are obviously important, for every expert there are thousands of average anglers and growing numbers of novice anglers. It is likely that the development of efficient, well-made, yet moderately priced tackle that is simple to operate and maintain has tilted the odds in the average anglers' favor over the years, and will probably continue to do so as new, even more advanced fishing equipment is developed.

Although there are few quantitative data on the relative efficiency of old versus new gear, it is obvious that saltwater fishing equipment has definitely changed, with the most dramatic developments occurring after World War II. The postwar years were also a time of rapid and tremendous growth in California. Between 1940 and 1970, the State's population tripled and so did the per capita income of its people. More spendable income and more leisure time undoubtedly contributed to the saltwater angling boom in California, and to an increased demand for angling products and services and better dissemination of angling information.

Changes in fishing methods, as well as tackle, also have been observed in saltwater sport fishing in California (Fig. 15). In just 8 years (1957-65), striped bass sportfishing boat methods in San Francisco Bay changed from bait fishing to deep-line trolling to live-bait drifting. Within only a few years, ocean surf casters, who had for years still-fished with bait for striped bass, switched to casting artificial lures. The sturgeon fishery received a tremendous boost when, in the 1960's, grass shrimp was discovered as an effective bait. In the 1970's, the development of successful methods to catch sturgeon on the herring spawning grounds essentially opened up a new fishing area for this species in San Francisco Bay. Multijig terminal tackle has largely replaced the standard bait rig in offshore bottomfishing in northern California. Development of lightweight synthetic fishing lines, dependable fishing reels and rods, and improvements in boat design and equipment have all changed the style of marine sport fishing in California. No doubt many other California recreational fisheries not mentioned in this report have been similarly affected by changing methods as well as by new kinds of tackle.

Because angler efficiency may also be altered when such changes occur, these factors should be considered when biologists assess relative abundance using catch-per-unit-of-effort data. Changes in methods or tackle may not only affect the catch of target species, but also that of incidentally caught speices.

Ideally, information on relative efficiency should be obtained when a fishery undergoes significant changes in gear or methods, but if this is not possible, these changes should at least be monitored as closely as possible and taken into account when estimating, through effort units, relative abundance of marine game fish populations.

Acknowledgments

Without the cooperation and advice of those I interviewed—veteran anglers, members of the tackle industry, sport boat skippers and others connected with the marine recreational fishing industry—this chronology would not have been possible. I am also grateful to Norm Abramson, Arthur Agnew, Charles Davis, Jr., Roger Green, Daniel Miller, Ed Neal, and George Reiger for reviewing the manuscript and offering many helpful suggestions. Joe Lesh and Dan Gotshall helped by providing needed information on north coast salmon fishing.

Literature Cited

A. P. B. 1908. Fishing in California. Forest and Stream, October 10, 1908, p. 581.

Cannon, R. 1964. How to fish the Pacific Coast. Lane Publ. Co., Menlo Park, Calif., 337 p.

Chadwick, H. K. 1962. Catch records from the striped bass sport-fishery in California. Calif. Fish Game 48:153-177.

———, and A. B. Albrecht. 1965. The summer and fall striped bass fishery during 1960 and 1961. Calif. Dep. Fish Game, Inland Fish. Branch, Admin. Rep. 65-11, 27 p.

Collins, J. W. 1892. Report on the fisheries of the Pacific Coast of the United States. Rep. U.S. Comm. Fish Fish. 1888(Part II):3-269.

Croker, R. S. 1938a. Historical account of the Los Angeles mackerel fishery. Calif. Dep. Fish Game, Fish Bull. 52, 62 p.

———. 1938b. Let's go fishing. Calif. Fish Game 24:280-287.

Davis, J. C., II. 1949. California salt water fishing. A.S. Barnes & Co., N.Y., 271 p.

French, D. G. 1916. Fishing at Santa Catalina Island—its development and methods. Calif. Fish Game 2:14-19.

Frey, H. W. (editor). 1971. California's living marine resources and their utilization. Calif. Dep. Fish Game, Sacramento, 148 p.

Fry, D. H., Jr. 1931. The ring net, half ring net, or purse lampara in the fisheries of California. Calif. Dep. Fish Game, Fish Bull. 27, 65 p.

Garrison, C., and B. Rice. 1972. Saltwater fishing: Beginner to expert. Fenwick/Sevenstrand, Westminster, Calif., 80 p.

[5]A plastic or metal plate clamped on the lower part of the rod shaft and rested on the boat railing for better leverage when reeling in.

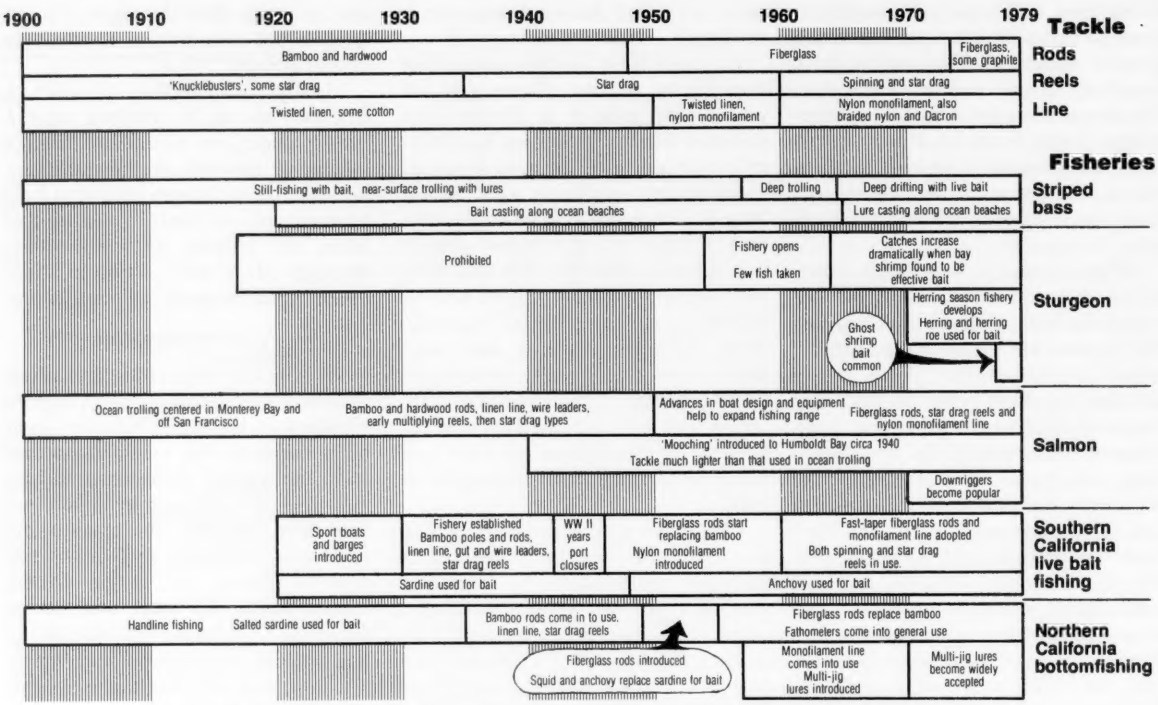


Figure 15.—Chronology of some changes in saltwater angling methods and gear in California. (Demarcation lines for changes are approximate.)

Gulland, J. A. 1968. Appraisal of a fishery. *In* W. E. Ricker (editor), Methods for assessment of fish production in fresh waters. IBP Handb. No. 3, p. 236-245. Blackwell Sci. Publ., Oxford, Engl.

Haw, F., H. O. Wendler, and G. DeChamps. 1967. Development of Washington State salmon sport fishery through 1964. Wash. Dep. Fish., Res. Bull. 7, 192 p.

Holder, C. F. 1908. Sport fishing in California and Florida, Bull. Bur. Fish. 28(Part I):201-210.

________. 1914. Attempts to protect the sea fisheries of southern California. Calif. Fish Game 1:9-19.

Hull, C. 1973. Newport Bay in '45. Salt Water Sportsman 34(10):28-29, 50-52.

________. 1974. California—back when. Salt Water Sportsman 35(2):32-33, 53-55.

Jordan, D. S., and B. W. Evermann. 1902. American food and game fishes, 1st ed. Doubleday, Page & Co., N.Y., 573 p.

Major, H. 1948. Salt water fishing tackle. Funk and Wagnalls Co., N.Y., 284 p.

Marden, L. 1965. Angling in the United States. *In* Wondrous world of fishes, p. 54-85. National Geographic Society, Wash., D.C.

McClane, A. J. 1974. Spinning. *In* A. J. McClane (editor), McClane's new standard fishing encyclopedia, p. 922-937. Holt, Rinehart and Winston, N.Y.

McKechnie, R. J., and R. B. Fenner. 1971. Food habits of white sturgeon, *Acipenser transmontanus*, in San Pablo and Suisun Bays, California. Calif. Fish Game 57:209-212.

Melner, S., and H. Kessler (editors). 1972. Great fishing tackle catalogs of the golden age. Crown Publ. Inc., N.Y., 344 p.

Miller, D. 1974. Fishing the surf. Outdoor Calif. 35(5):10-12.

Miller, D. J., and D. Gotshall. 1965. Ocean sportfish catch and effort from Oregon to Point Arguello, California, July 1, 1957-June 30, 1961. Calif. Dep. Fish. Game, Fish Bull. 130, 135 p.

Miller, L. W. 1972. White sturgeon population characteristics in the Sacramento-San Joaquin estuary as measured by tagging. Calif. Fish Game 58:94-101.

Moss, F. J. 1976. Modern saltwater fishing tackle. International Marine Publishing Co., Camden, Maine, 322 p.

Neal, E. 1977. Spooning for salmon. San Francisco Examiner, Tues. Feb. 22, 1977, p. 43.

Pinkas, L. 1977. California marine fish landings for 1975. Calif. Dep. Fish Game, Fish Bull. 168, 55 p.

Sadler, R. J. 1928. Fishing off southern beaches growing in popularity. Calif. Fish Game 14:250.

Scofield, W. L. 1929. Sardine fishing methods at Monterey, California. Calif. Dep. Fish Game, Fish Bull. 19, 61 p.

________. 1947. Drift and set line fishing gear in California. Calif. Dep. Fish Game, Fish Bull. 66, 38 p.

________. 1948. Trawling gear in California. Calif. Dep. Fish Game, Fish Bull. 72, 60 p.

________. 1951a. Purse seines and other roundhaul nets in California. Calif. Dep. Fish Game. Fish Bull. 81, 83 p.

________. 1951b. An outline of California fishing gear. Calif. Fish Game 37:361-370.

________. 1956. Trolling gear in California. Calif. Dep. Fish Game, Fish Bull. 103, 45 p.

Smith, H. M. 1895. Notes on a reconnoissance of the fisheries of the Pacific coast of the United States in 1894. Bull. U.S. Fish. Comm. 14:223-288.

Squire, J. L., Jr., and S. E. Smith. 1977. Anglers' guide to the United States Pacific coast. U.S. Dep. Commer., NOAA, Natl. Mar. Fish Serv., Wash., D.C., 139 p.

Van Deventer, W. C. 1926. Barge fishing on the southern California coast. Calif. Fish Game 12:19-20.

Wainwright, D. L. 1965. The fisheries of Humboldt County from 1854 to 1892. Humboldt State Univ. Library, Arcata, Calif., 129 p. (Mimeo report based on articles in the *Humboldt Times*, 1854-1892.)

Wendler, H. O. 1960. The importance of the ocean sport fishery to the ocean catch of salmon in the states of Washington, Oregon and California. Calif. Fish Game 46:291-300.

Whitehead, S. S. 1931. Fishing methods for the bluefin tuna (Thunnus thynnus) and an analysis of the catches. Calif. Dep. Fish Game, Fish Bull. 33, 32 p.

Whittier, B. 1976. A brief history of power in pleasure boats. Natl. Fisherman Yearb. Issue 56(13):98-103.

Young, P. H. 1969. The California partyboat fishery 1947-1967. Calif. Dep. Fish Game, Fish Bull. 145, 91 p.

Editorial Guidelines for *Marine Fisheries Review*

Marine Fisheries Review publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under completed NOAA Form 25-700.

Manuscripts must be typed (double-spaced) on high-quality white bond paper and submitted with two duplicate (but not carbon) copies. The complete manuscript normally includes a title page, a short abstract (if needed), text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1½-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

Style

In style, *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 6, "A List of Common and Scientific Names of Fishes from the United States and Canada," third edition, 1970. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

Tables and Footnotes

Tables and footnotes should be typed separately and double-spaced. Tables should be numbered and referenced in text. Table headings and format should be consistent; do not use vertical rules.

Literature Citations

Title the list of references "Literature Citations" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, the year and month and volume and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted. Include the title, author, pagination of the manuscript or report, and the address where it is on file. For personal communications, list the name, affiliation, and address of the communicator.

Citations should be double-spaced and listed alphabetically by the senior author's surname and initials. Co-authors should be listed by initials and surname. Where two or more citations have the same author(s), list them chronologically; where both author and year match on two or more, use lowercase alphabet to distinguish them (1969a, 1969b, 1969c, etc.).

Authors must double-check all literature cited; they alone are responsible for its accuracy.

Figures

All figures should be clearly identified with the author's name and figure number, if used. Figure legends should be brief and a copy may be taped to the back of the figure. Figures may or may not be numbered. Do not write on the back of photographs. Photographs should be black and white, 8- × 10- inches, sharply focused glossies of strong contrast. Potential cover photos are welcome but their return cannot be guaranteed. Magnification listed for photomicrographs must match the figure submitted (a scale bar may be preferred).

Line art should be drawn with black India ink on white paper. Design, symbols, and lettering should be neat, legible, and simple. Avoid freehand lettering and heavy lettering and shading that could fill in when the figure is reduced. Consider column and page sizes when designing figures.

Finally

First-rate, professional papers are neat, accurate, and complete. Authors should proofread the manuscript for typographical errors and double-check its contents and appearance before submission. Mail the manuscript flat, first-class mail, to: Editor, *Marine Fisheries Review*, Scientific Publications Office, National Marine Fisheries Service, NOAA, 1107 N.E. 45th Street, Room 450, Seattle, WA 98105.

The senior author will receive 50 reprints (no cover) of his paper free of charge and 100 free copies are supplied to his organization. Cost estimates for additional reprints can be supplied upon request.

☆GPO 696-359

UNITED STATES
DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE
SCIENTIFIC PUBLICATION OFFICE
MARINE FISHERIES REVIEW
ROOM 450
1107 N.E. 45TH ST.
SEATTLE, WA 98105

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE
COM-210

Controlled Circulation Rate

U.S.MAIL

MFR UNIVM300UFISSDUE007R 1
UNIV MICROFILMS INTL
SERIALS PROCESSING
300 N ZEEB RD
ANN ARBOR MI 48106